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A

MANUAL OF ELECTRICITY,

PRACTICAL AND THEORETICAL.

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ELECTRICITY,

PRACTICAL AND THEORETICAL.

BY

Frederick
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PREFACE.

THE important position which Electricity now holds among the physical sciences, and the highly valuable purposes to which it is applied, make it particularly desirable that the student of natural philosophy should have the means of attaining, in a *compendious* form, a knowledge of the progress of electric science to the present day, and of comprehending its varied phenomena and applications. In this Manual of Electricity it has, therefore, been the author's object to set forth clearly, yet concisely, the prominent points in the history of the science, and to notice and explain those actions of this peculiar force which indicate its special attributes, and give interest to its study.

In attempting to comprise all that is important to be known of the history, the phenomena, and the applications of electricity within a single volume, there is considerable risk of producing a mere chronological record, and an explanatory catalogue, rather than an interesting treatise. When, indeed, it is considered that Priestley's *History of Electricity* occupies a thick quarto volume—though written before the most important sources of electric force had been revealed by Galvani and Volta, by Œrsted, Seebeck, Faraday, and Armstrong—it might be supposed that a history which includes those discoveries, and is contained in little more than fifty pages, must be only a barren sketch. To afford space for circumstantial illustration and *explanatory remarks*, attention has been concentrated on the *characteristic* facts, by the adoption of which course it is hoped

that the historical notice of the advancement of electric science will be found interesting as well as instructive.

As a mere statement of effects would have proved unsatisfactory without an explanation of the causes that produce them, such explanations have been given as appeared to the author to afford the clearest insight into the nature of electrical action. The Franklinian theory of the excitement of frictional electricity has been generally adopted, because it is the most simple, and voltaic action has been attributed to chemical agency; but theoretical discussions have been avoided as much as possible, lest they might tend to obscure rather than to throw light on the causes of electrical phenomena. In some few instances views have been taken of the action of electric force different from those commonly entertained; but in such cases the reasons for the departure from received opinions have been fully stated.

The author is not aware that the many varied inventions for the application of electric power to the uses of man have been previously described collectively. In noticing them, prominence has been given to those objects that are of the greatest importance; it having been considered sufficient in appliances of less consequence merely to indicate the mode of operation, and to explain the principles of their action.

By dividing the consideration of electric science into its history, phenomena, and applications, some repetitions have almost unavoidably occurred, in order to make each part complete in itself. It is conceived, however, that the advantages attending such an arrangement, by affording a clearer conception of each branch of the subject, more than counterbalance the inconvenience of occasionally going, for a short distance, over the same ground.

Haverstock Terrace, Hampstead,
December, 1856.

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HISTORY OF ELECTRICITY.

ELECTRICITY.

CHAPTER I.

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THERE requires no deep research in the pages of antiquity to trace the rise and progress of the science of electricity. It sprang into being in comparatively recent times; and after the first halting-stages of its existence were surmounted, it advanced from infancy to manhood with the rapidity of its own lightning spark; and though not yet arrived at maturity, it has attained a degree of importance not surpassed by any of the physical sciences.

Some of the ordinary phenomena of electricity, indeed, attracted observation from the earliest periods. Not to mention lightning and its accompanying thunder, the excitement of sparks by the rubbing of furs must have been noticed, and wondered at, by the nomad tribes who first inhabited the earth. The earliest recorded observation of electrical phenomena, however, occurs 600 years before the Christian era. About that time, it is stated that Thales, of Miletus, one of the seven sages of Greece, remarked that amber, when rubbed, attracted light bodies to its surface. This seems to have been the extent of his observation; but the fact afforded ample matter for speculation. He conceived that amber must possess some inherent living principle, called into action by friction, and that when thus excited it emitted an invisible effluvium, which was constantly returning to the animated amber, and bringing back with it those substances that were not too heavy to resist its adhesive force.

The next recorded notice of electrical attraction is by Theophrastus, 300 years afterwards, who remarked that the crystal called by him *lyncurium*, supposed to be tourmalin, attracted light bodies to its surface.

The shock given by the torpedo is mentioned by Pliny; but that phenomenon was not, until the middle of the last century, imagined to have any connection with the attractive properties of amber and tourmalin. Some very remarkable facts are also mentioned by Eustathius, who lived in the fifth century of the Christian era. He states that a freedman of Tiberius was cured of the gout by the shock of the torpedo. This is the first recorded instance of the application of electricity to medical purposes, and, if authentic, electricity was much more efficacious in those days than in its application as a curative in modern times. Eustathius further relates, that Wolimer, king of the Goths, was able to emit sparks from his body; and that a certain philosopher, whilst dressing and undressing, emitted flashes of light.

There is a void of nearly 1,200 years ere we find any other distinct notice of electrical phenomena. The subject must, however, during that period, have attracted attention; for at the beginning of the seventeenth century, a book by Dr. Gilbert was published, entitled *De Magnete*, in which many other substances besides amber and tourmalin are mentioned as having the property of attracting light bodies when rubbed. As amber was the substance first noticed to possess that property, its Greek term *electron* had precedence in giving a name to the infant science of electricity.

When we consider that previously to the announcement of Dr. Gilbert's discoveries, the only known electrics were amber, tourmalin, and jet, the accessions he made to the number must be regarded as an important step in the progress of electricity. He added at least twenty to the list of electrics, including most of the precious stones, glass, sulphur, sealing-wax, and rosin; and he determined that those substances, when rubbed under favourable circumstances, attract not only light floating bodies, but all solid matters whatever, including metals, water, and oil. He observed also that the conditions most favourable to the excitement of the attractive power are, a dry state of the atmosphere, and a brisk and light friction; whilst moist air and a southerly wind he found to be most prejudicial to the production of electrical effects.

The deductions of Dr. Gilbert from his experiments were in many instances curiously fallacious. In pointing out, for instance, the distinction between magnetic and electric attraction,

he affirmed that magnets and iron mutually attracted each other; but that when an electric was excited, it alone exerted attractive power, the substances attracted being inactive. He noticed, also, as a special distinction between magnetism and electricity, that the former repelled as well as attracted, whilst the latter only attracted.

After the discoveries and investigations of this father of electric science, there was a lapse of about sixty years with scarcely any progress. Mr. Boyle is the next person whose investigations are worth mention. Though he repeated and confirmed former experiments, and devoted much time to the subject, he did little more than add some few to the number of electrics. This philosopher has, indeed, the reputation of being the first who perceived light issuing from an excited electric, but his notice of it was so indistinct that he can scarcely be said to be the discoverer of the luminous property of electricity.

Mr. Boyle's theory of electrical attraction was similar to that of Thales. He, as well as the Greek sage, conceived that the excited electric emitted a glutinous effluvium which laid hold of small bodies in its progress, and on returning, carried them with it. This theory was advocated by other electricians at the time, and experiments were made, and are recorded in the *Philosophical Transactions*, which were considered to prove the emission of glutinous particles from excited electrics.

The most important advances in the science at that period, were made by Otto Guericke, burgomaster of Magdeburg, the inventor of the air-pump, who invented also the first electrical machine.

The apparatus with which electricians had experimented till near the end of the seventeenth century was of the most simple kind. A rod or flat surface of glass, rosin, or sulphur, rubbed with the hand or with a piece of woollen, was their best means of exciting electricity. It may therefore be supposed that the quantity at any time under observation was very small. Otto Guericke constructed an apparatus by which the quantity of electricity excited was greatly augmented. It consisted of a sulphur globe, whirled round on an axis, whilst he held his hand to it to serve as a rubber. Sulphur, it may be remarked, was a favourite electric with early experimenters, as it was imagined that electricity was emitted with the sulphurous effluvium produced by the friction. In the construction of M. Otto Guericke's electrical machine, for example, he cast the sulphur in a glass globe, and then broke the glass in order to expose the sulphur to the action of the rubber. With this machine, *rude as it was*, Otto Guericke excited much greater

quantities of electricity than had previously been produced; and he was thus enabled not only to see flashes of light, but to hear the snapping noise of the electric spark.

It may seem extraordinary that the most commonly observed phenomenon of electricity had not been before noticed as a property pertaining to electrical bodies. It should be borne in mind, however, that furs and silks, from the friction of which sparks are so frequently emitted, had not been classed as electrics, and the only property of electricity then known was that of attraction. It was not likely, therefore, until the two phenomena of attraction and the emission of light were observed combined in the same substance, that the excitement of sparks by friction should be considered due to electricity.

To Otto Guericke must also be conceded the honour of having discovered the property of electric repulsion. He ascertained that a feather, when attracted to an excited electric, after adhering to it for a short time, is repelled from the surface, and that it will not again approach until it has touched some other body to which it can part with the electricity it contains. He observed, also, that a feather when thus repelled by an excited electric, always keeps the same side presented towards it. The correspondence between this fact and the position of the moon towards the earth, induced some speculative philosophers to assume that the revolution of the moon round the earth might be caused by electrical attraction and repulsion.

The discoveries of Sir Isaac Newton, shortly afterwards, dispelled this notion, and so far engaged the attention of scientific inquirers, that electricity for a time remained in abeyance. Newton had, indeed, paid a passing attention to electrical phenomena, but the only addition made by him to the facts before collected was, that electric attraction and repulsion penetrate through glass. He made known, for instance, that when a plate of glass is excited on one side, the other side also becomes electrical.

About the same time that Otto Guericke obtained decisive evidence of the luminous properties of electricity, the fact was made more strikingly manifest by Dr. Wall, who operated with a stick of amber of large dimensions. He used a piece of woollen cloth for a rubber, and appears to have been remarkably successful in eliciting by that means a greater amount of electricity than had been excited even with the sulphur globe of Otto Guericke.

The first idea of resemblance between electrical phenomena and thunder and lightning was suggested to Dr. Wall by the *apparently* remote analogy of the crackling sounds and sparks

emitted by that large stick of amber. The observation deserves to be recorded in his own words: "From the friction of the amber a prodigious number of little cracklings were heard, and every one of these produced a little flash of light. And what to me is very surprising, upon its eruption it strikes the finger very sensibly, wheresoever applied, with a push or a puff like wind. The crackling is full as loud as charcoal on fire; and five or six cracklings or more, according to the quickness of placing the finger, have been produced from one single friction, light always succeeding each of them. *This light and crackling seem in some degree to represent thunder and lightning.*"

Little further progress was made for nearly forty years. During that interval, the accumulation of facts and improvements in the apparatus was slow and insignificant. As yet, experimenters had worked without any system, and without in the least comprehending the principles on which the effects they produced depended. It was not until 1729—nearly 130 years after the first book on the science had been published—that the distinction between conductors and non-conductors of electricity was discovered. This important fact was accidentally ascertained by Mr. Stephen Grey, whilst attempting to communicate electricity to a cord suspended by threads. His first experiments were unsuccessful because he suspended the cord by threads that conducted the electricity from the cord nearly as quickly as it entered. It was then suggested by Mr. Wheeler, who assisted at the experiment, that the cause of the escape of the electricity was the thickness of the packthread employed, and he recommended that silken threads should be tried, because, being much thinner, it was supposed the electric fluid would not be able to flow through it so readily. Accordingly the silk thread was tried, and with great success.

So little were the experimenters aware that the difference in the effects was caused by the different conducting properties of the substances employed, and so impressed were they with the notion that success with the silk suspenders was entirely owing to their superior fineness, that they endeavoured to obtain still better results by suspending the cord on very fine *wires*. The total failure of the experiment in this case induced them at length to consider that there must be a difference in the conducting properties of the substances employed.

The attention of electricians having been thus directed to this subject, light was gradually, and still feebly, thrown on the causes of success and failure in their experiments under different circumstances. Lists of conducting and of non-conducting substances were made, when it was found that glass, rosin, and all

bodies known as electrics, were bad conductors of electricity, and that those in which electricity could not be excited were conductors. In the conducting and non-conducting properties of these substances great differences were soon detected; glass and rosin being the worst conductors, and metals the best.

Nearly contemporaneously with the discovery of the different conducting properties of electrics and non-electrics was the announcement that M. Du Fay, intendent of the French king's gardens, had detected the existence of two distinct kinds of electricity. This, like all the other discoveries hitherto made, originated from accidental circumstances. A piece of gold leaf having been repelled from an excited *glass* rod, M. Du Fay pursued it with an excited rod of *sealing wax*, expecting that the gold leaf would be equally repelled by that electric. His astonishment was great on seeing the gold leaf attracted to the wax. On repeating the experiment he found the same result invariably to follow: the gold leaf when repelled from glass was attracted by rosin; and when repelled from the latter was attracted by glass. Hence M. Du Fay assumed that the electricity excited by the two substances was of different kinds; and as one was produced from glass, the other from rosin, he distinguished them by the names *vitreous* and *resinous* electricity.

It is a curious fact that M. Du Fay, the discoverer of this important property of electricity, afterwards repudiated his own discovery. Subsequent experiments and consideration induced him to depart from the truth he had developed, and to imagine that the effects observed arose entirely from difference in the degrees of force exerted by different electrics; the more powerful attraction of the one overcoming the feeble repulsion of the other. It is difficult to conceive how he could have thus retrograded from the position he had established. For supposing the gold leaf when repelled from the excited glass to have been attracted to the rosin by superior electrical force, this superiority of force could not have afterwards yielded to the weaker attraction of the glass; yet the mutual interchange of attractive and repellent power must have been frequently noticed. Other investigators, however, confirmed the fact M. Du Fay had discovered and thus singularly renounced; and the original terms "vitreous" and "resinous" electricity continue to be retained by a majority of electricians.

One of the experiments devised about this period, which excited great astonishment, and tended materially to direct the attention of philosophic inquirers to the subject of electricity, was the development of sparks from the human ... Grey

having suspended a boy with hair lines, and communicated electricity to him by means of an excited glass tube, sparks were then drawn from all parts of the boy's body. This phenomenon —depending simply on the fact that the bodies of animals are conductors of electricity in consequence of the fluids they contain—was conceived to be owing, in some mysterious manner, to a connection between the electric effluvium, as it was called, and the vital principle. M. Du Fay suspended himself in a similar manner for the purpose of experiencing the sensation, and when the more convenient mode of insulation by standing on a cake of rosin, or on a glass stool, was introduced, the experiment became the most popular in the range of electrical phenomena.

About the middle of the eighteenth century, the investigation of these phenomena was undertaken by several scientific inquirers in Germany. M. Boze, Professor of Philosophy at Wittemburg, made considerable improvement in the mode of exciting electricity, by the addition of metal conductors to the revolving glass globes of his machines. In the first instance his conductor was held by a man, insulated by standing on a cake of rosin. He shortly afterwards adopted the more convenient method of supporting the conductor by means of silk cords; and to facilitate the passage of the electricity from the excited globe, he added a number of linen strings to the conductor, which served the purpose, though very imperfectly, of the metal points subsequently used. M. Boze and other experimenters adopted the plan of increasing the quantity of electricity excited, by bringing several globes into action at the same time, and collecting the products of the globes in one conductor. With these instruments they are stated to have produced effects which seem incredible with such imperfect apparatus, and the accounts given of the results must be greatly exaggerated. It is stated, for instance, that by sparks from these electrical machines blood was drawn from the finger; that they produced a sensible shock extending from the head to the feet; and that they were sufficiently powerful to kill small birds. Even with the improved electrical machines of the present day, with the addition of metal points and amalgamated rubbers, at that time unknown, nothing approaching these effects can be produced.

Of the experiments performed by the continental philosophers at this period, none excited so much general interest as the setting on fire of inflammable substances. This was first accomplished by Dr. Ludolph of Berlin; and the experiment was quickly repeated and improved on in different parts of Europe. The inflammation of spirits of wine, and of phosphorus, by an *electric spark emitted from* the finger of a person insulated by

standing on rosin, was considered so extraordinary, that it not only called the attention of men of science to this branch of natural philosophy, but the exhibition of this, and of other electrical wonders became a very popular public entertainment.

Quickly following the development of the igniting powers of the electric spark was the discovery of the Leyden phial, the most astonishing of any of the electrical phenomena then made known, and which opened an entirely new field for scientific investigation.

For the honour of being the original discoverer of the Leyden phial there were several claimants, as is generally the case with important discoveries and inventions. It is commonly attributed to M. Cuneus of Leyden, at the beginning of the year 1746. Like all the antecedent discoveries, that of the Leyden jar was the effect of accident—so far, at least, as M. Cuneus was concerned. It occurred to him whilst repeating a well-devised experiment of Professor Muschenbrœck for collecting and confining the "electric effluvium." The professor conceived, if he could impart electricity to a conducting substance entirely surrounded by non-conductors, that it would be thereby prevented from being dissipated, and the force might be concentrated. The most convenient form of trying the experiment appeared to be to electrify water contained in a glass bottle, connection with the conductor of the machine being established by an iron nail passing through the cork into the water. The experiment, however, was not attended with any apparent results to Professor Muschenbrœck. The object he contemplated was, indeed, partly accomplished, but the accumulation of electricity in the phial was not manifested, owing to the want of a conducting surface on the outside by which it could be concentrated. M. Cuneus, in repeating the experiment, happened to grasp the bottle with his hand, which thus served for the requisite conducting surface outside the glass, and when with the other hand he endeavoured to disengage the nail from the conductor of the machine, he was startled by receiving a smart shock through his arms. Professor Muschenbrœck renewed the experiment, with the advantage of the experience of M. Cuneus, and with equal success. In these experiments with the Leyden phial, and for a considerable time afterwards, the bottle was always grasped by the hand, the cause of its producing the effect not being understood.

Though M. Cuneus acquired the reputation of being the discoverer of the Leyden phial, the claim of M. Von Kleist, dean of the Cathedral of Camin, to be the first discoverer, rests on strong ground. It is stated that he sent an account of the discovery

to Dr. Leiberkuhn of Berlin, on the fourth November, 1745. This account, communicated to the Academy of Berlin, and entered among their proceedings, is to the following effect: "When a nail or a piece of thick brass wire is put into a small apothecary's phial and electrified, remarkable effects follow; but the phial must be very dry or warm. I commonly rub it over beforehand with a finger on which I put some pounded chalk. If a little mercury, or a few drops of spirit of wine be put into it, the experiment succeeds the better. As soon as this phial and nail are removed from the electrifying glass, or the prime conductor to which it has been exposed is taken away, it throws out a pencil of flame so strong, that with this burning instrument in my hand I have taken above sixty steps in walking about my room. When it is electrified strongly, I can take it into another room, and there fire spirits of wine with it. If, whilst it is electrifying, I put my finger, or a piece of gold which I hold in my hand, to the nail, I receive a shock which stuns my arms and shoulders. A tin tube, or a man, placed upon electrics, is electrified much more strongly by this means than in the common way. When I present this phial and nail to a tin tube which I have, fifteen feet long, nothing but experience can make a person believe how strongly it is electrified. Two thin glasses have been broken by the shock. It appears to me very extraordinary that when this phial and nail are in contact with either conducting or non-conducting matter, the strong shock does not follow. I have cemented it to wood, glass, sealing-wax, metal, &c., which I have electrified without any great effect. The human body, therefore, must contribute something to it. This opinion is confirmed by observing that unless I hold the phial in my hand, I cannot fire spirits of wine with it."

The foregoing account of M. Von Kleist's experiments clearly shows that he had stumbled on the same discovery as M. Cuneus; and the date is previous to the experiment of the latter. It appears, however, that the dean was not aware of the full importance of grasping the bottle with his hand, and his description of the experiments was so vague, that several philosophers to whom he communicated the discovery were unsuccessful in their attempts to repeat them.

The physiological effects of the Leyden phial were those that naturally excited most attention in the first instance. The accounts given by some of the early experimenters of the sensation of the electric shock exhibit curious illustrations of the exaggeration caused by the terror of this novel agitation of the nervous system. The small and inefficient apparatus experi-

mented with could have produced only very feeble shocks, yet the effects are represented to have been little less than those of a flash of lightning. These exaggerations are the more remarkable, when it is borne in mind that they proceeded from eminent philosophers accustomed calmly to investigate physical phenomena. M. Muschenbrœck, for example, says in a letter to M. Reaumur, that he felt himself struck in his arms, shoulders, and breast, so that he lost his breath, and was two days before he recovered from the effects of the blow and the terror. He adds, that he "would not take another shock for the whole kingdom of France."

M. Allamand, a fellow-professor with M. Muschenbrœck, and who assisted in the experiments which led to the discovery, stated that he lost his breath for some moments after taking the first shock; and that he felt so intense a pain along his right arm, that he apprehended serious consequences from it. Another distinguished electrician, Professor Winckler of Leipsic, said that the first time he tried the experiment his body was greatly convulsed, and that it put his blood into such violent agitation that he was apprehensive of an ardent fever, and was obliged to take refrigerating medicines. He also felt great heaviness in his head, as if a stone were laid upon it. On two other occasions he said the shock made his nose bleed, to which he had not been previously disposed.

The astonishing effects of the electric shock were calculated to draw public attention to the subject of electricity more than any previous discovery. Every one was anxious to see the effects and to experience the new sensation, notwithstanding the terrible accounts given of it. Travelling showmen with their Leyden phials and electrical machines were to be seen in all parts of Europe, who found profitable employment in exhibiting that and other striking electrical phenomena. Nor were philosophers idle in the new field of inquiry which this discovery opened to their investigation. The properties of the Leyden phial were closely examined; the conditions requisite to the development of the phenomena were better understood; and many ingenious, though fallacious, theories were devised for their explanation. The construction of the apparatus was improved by the addition of an outside metallic coating, and jars were substituted for bottles, by which means a metallic lining could be applied also to the inside of the glass.

Many interesting experiments were made that exemplified still more strongly the powerful action of electricity, and the rapidity of its transmission. The shock was communicated at the same *instant through 180* of the French guards, in the presence of the

King of France, by joining their hands in a connected chain; the soldier at one end touching the outside of the jar, and the man at the other end touching the wire connected with the inside coating.

By combining several jars together to form an electrical battery, the force was greatly accumulated. By that means all kinds of inflammable substances were set on fire, fine wires and gold leaf were deflagrated, and small animals were killed by the electric shock.

Though the feeble shocks of the small phials employed in the early stages of the discovery created such an exaggerated state of nervous apprehension, and produced, as we are told, such distressing effects, yet a few years afterwards we find electricians receiving shocks of really formidable power with remarkable stoicism, and giving similar charges to others, in a manner that would now be considered highly dangerous. Dr. Franklin, for instance, experimented with glass jars containing six gallons each; and whilst trying the destructive power of the electric shock on some fowls, he inadvertently received the full charge of two of these very large jars through his arms and body. The effects, as he describes, were "sufficiently severe;" yet he merely mentions the accident as showing that a man can bear without much detriment a shock greater than he had imagined. He said that on receiving the shock, it seemed like a universal blow through the body from head to foot, and was followed by a violent quick trembling in the trunk, which went off gradually in a few seconds. It was some minutes before he could collect his thoughts so as to know what was the matter; for he did not see the flash, though his eye was on the prime conductor, nor did he hear the crack, nor did he particularly feel the stroke on his hand, though it raised a small swelling there. His arms and the back of his neck felt somewhat numbed the remainder of the evening, and his breast was sore for a week after, as if it had been bruised.

Electricians of the present day would not venture to repeat such an experiment as the following, of which an account is given by Franklin in a letter dated Philadelphia, 1755:—"The knocking down of six men was performed with two of my large jars, not fully charged. I laid one end of my discharging-rod upon the head of the first; he laid his hand on the head of the second; the second his hand on the head of the third, and so to the last, who held in his hand the chain that was connected with the outside of the jars. When they were thus placed, I applied the other end of my rod to the prime conductor, and they all *dropped together.* When they got up, they all declared they

had not felt any stroke, and wondered how they came to fall; nor did any of them either hear the crack or see the light of it. You suppose it a dangerous experiment; but I had once suffered the same myself, receiving by accident an equal stroke through my head that struck me down without hurting me; and I had seen a young woman that was about to be electrified through the feet (for some indisposition) receive a greater charge through the head by inadvertently stooping forward to look at the placing of her feet, till her forehead (as she was very tall) came too near my prime conductor: she dropped, but instantly got up again, complaining of nothing. A person so struck sinks down doubled, or folded together as it were, the joints losing their strength and stiffness at once, so that he drops on the spot where he stood instantly, and there is no previous staggering, nor does he ever fall lengthwise. Too great a charge might, indeed, kill a man, but I have not yet seen any one hurt by it. It would certainly, as you observe, be the easiest of all deaths."

With the powerful batteries employed by Franklin he also succeeded in communicating magnetism to steel needles. This had, indeed, been previously done by others, but not in so satisfactory a manner.

Numerous experiments were undertaken by Dr. Watson, Lord C. Cavendish, and other gentlemen associated with them, for the purpose of ascertaining the rapidity of the electric discharge, and the distances it could be transmitted through water and dry ground. In one of these experiments, performed in 1747, an electric discharge was sent across the Thames; and in another, near Shooter's hill, the discharge passed instantaneously through two miles of wire and two miles of dry ground without any perceptible interruption.

These experiments deserve special notice at the present day, as they established the fact of the conducting property of the earth, which has been turned to good account in the construction of electric telegraphs. Another fact also intimately bearing on the same subject was ascertained by Signor Beccaria, viz., that water is an imperfect or a good conductor of electricity in proportion to its quantity. This conclusion was drawn from experiments in sending electric discharges through tubes of different sizes filled with water. In these experiments it was ascertained that a charge which passed freely through the larger was obstructed by the smaller tubes.

Numerous speculations were broached to account for the phenomena of the Leyden phial, but the nature of its action was very imperfectly understood until Dr. Franklin undertook the investigation. It had, indeed, been discovered that a jar

could not be charged whilst it was insulated from the earth; but this circumstance, which afforded a clue to the elucidation of the phenomena of the Leyden phial, remained a barren fact until it attracted Franklin's observation. He was the first to discover that the electricity on the outside of the jar is of a different kind from that within; and that in charging a jar, a quantity of electricity is expelled from one side of the glass equal to that introduced on the other. Hence the necessity of supplying a passage for the escape of the electricity outside by connecting it with a conducting substance. According to Franklin's view of the condition of a charged Leyden phial, the inside when charged from excited glass is filled with what had been termed vitreous electricity, and the outside is equally charged with electricity of the opposite kind. These electricities having a strong mutual attraction, and being kept asunder only by the resistance offered by the non-conducting glass and surrounding air, instantly rush together when the opposite surfaces are brought in connection, and thus produce all the phenomena of the Leyden phial; the glass, after the discharge of the electricity, being left in its original neutral condition.

Franklin also proved more satisfactorily than had previously been done, that the electric charge is in the glass, and not in the metallic coatings of the jar, and that the latter serve merely to conduct, and to concentrate to one point the electricity spread over the surface of the glass. To illustrate this fact most conclusively, he contrived a jar with loose metallic coatings, that could be removed and changed for others after the jar was charged. After this change was effected, the amount of electricity in the jar was found to be scarcely diminished.

The simple and beautiful theory of Franklin for explaining the action of the Leyden jar is one of the most important contributions of that philosopher to the science of electricity. Amplifying and improving the views that had previously been taken by Dr. Watson, he conceived that the friction of glass and of other electrics does not generate electricity, but that it causes a disturbance of the quantity of the electric fluid naturally inherent in electrics, producing thereby in some bodies an excess and in others a deficiency. The terms *positive* and *negative* were introduced to designate these states of repletion and want; and these terms have been generally adopted in this country in speaking of the two kinds of electricity. It will be observed that it forms an essential part of this theory to consider the phenomena of electricity as produced entirely by the disturbance of the equilibrium of the same etherial fluid, the particles of which are assumed to be mutually repulsive. On this principle

was explained the effect of bodies similarly electrified repelling each other, and the attraction of the opposite electricities was attributed to the force exerted in attempting to restore the equilibrium.

The application of this theory to explain the action of the Leyden jar affords a perfectly satisfactory view of the phenomena. When, for example, the wire connected with the interior coating is brought near the conductor of an electrical machine, the charged conductor makes an effort to part with a portion of its excess of the electric fluid to the jar; but the latter cannot receive an addition to its natural quantity inside until an equal quantity of that on the outside is expelled by means of some conducting body connected with the earth. When the electricity on the outside has been thus permitted to escape, the inside of the jar becomes positively electrified and the outside negatively, and in equal degrees. The resistance offered to the passage of the electric fluid by the uncovered portion of the glass and by the surrounding air, maintains the coerced condition of the electricity of the jar until the metallic surfaces are brought sufficiently near, by means of connecting conductors, to enable the attractive powers of the opposite electricities to overcome the interposed resistance.

The Franklinian theory of electricity is not without difficulties, especially in the explanation of repulsion from bodies electrified negatively. These difficulties have induced philosophers on the continent to adopt the vitreous and resinous theory of Du Fay. But the great simplicity of Franklin's hypothesis, and its accordance with those theories which have been established as affording the most satisfactory explanation of phenomena in other departments of science nearly related to electricity, have enabled it to maintain its ground in this country; and from the time of the announcement of Franklin's theory much clearer notions of the principles of electrical action were generally entertained.

CHAPTER II.

The identity of lightning and electricity pointed out—Effect of points on electrified bodies ascertained by Franklin—Suggested experiments on thunder clouds—Electricity drawn from the clouds in France—Franklin's electrical kite—Lightning-conductors invented—Dangerous experiments with lightning—Death of Professor Richmann—Beccaria's experiments on atmospheric electricity—Electrical induction discovered—The theory of vitreous and resinous electricity revived—Measurement of electric forces—Inventions of the torsion balance and of the electrophorus—Progress of discovery to the end of the eighteenth century.

WE now approach another important epoch in the history of electricity, in which Dr. Franklin's powers of philosophical research and his fertility of invention are eminently conspicuous.

The flashing light, and the snapping noise of the electric spark, had, as we have seen, induced some of the earliest electricians to imagine a similarity between those manifestations of electricity and the phenomena of thunder and lightning. Dr. Wall's allusion to this probable identity was suggested at a time when the known facts were so few as to have made the analogy seem merely fanciful, but the further development of electrical force, especially after the discovery of the Leyden phial, enabled experimenters more closely to imitate on a small scale many of the destructive effects of lightning.

The observations of the Abbé Nollet bear so close a relation to the truth, that they deserve to be recorded, as indications how well prepared philosophers at that time were for the subsequent discovery of Franklin. In his *Leçons de Physique* the Abbé says: "If any one should take upon him to prove from a well-connected comparison of phenomena, that thunder is in the hands of nature what electricity is in ours, that the wonders which we now exhibit at our pleasure are minor imitations of those great effects which frighten us, and that the whole depends upon the same mechanism; if it is to be demonstrated that a cloud prepared by the action of the winds, by heat, by a mixture of exhalations, &c., is opposite to a terrestrial object; that this is the electrified body, and at a certain proximity from that which is not,—I avow that this idea, if it was well supported, would give me a great deal of pleasure; and in support of it how many specious reasons present themselves to a man who is well acquainted with electricity! The universality of the electric matter, the readiness of its action, its inflammability, and *its activity in giving* fire to other bodies, its property of striking

bodies externally and internally even to their smallest parts, the remarkable example we have of this effect in the experiment of Leyden, the idea which we might truly adopt in supposing a greater degree of electric power, &c.; all these points of analogy which I have been some time meditating, begin to make me believe that one might, by taking electricity for the model, form to one's self in relation to thunder and lightning more perfect and more probable ideas than have been hitherto offered."

No one, however, had devised a means of ascertaining the identity of lightning and electricity until Franklin pointed out the way of drawing electricity from the clouds; nor would he probably have thought of the means of doing so but for an unsuccessful experiment made by his friend Mr. Hopkinson. That gentleman electrified an iron ball with a needle fixed to it, expecting to draw a stronger spark from the point, as from a kind of focus; but he was greatly surprised to find that, instead of increasing the intensity of the electricity, the point dissipated it altogether. He mentioned the failure of the experiment to Dr. Franklin, who immediately undertook to investigate the cause, and to determine the influence of points in attracting electricity. In repeating the experiment, he ascertained not only that the ball could not be electrified when a needle was fastened to it, but that when the needle was removed and the ball was charged with electricity, the charge was silently and speedily withdrawn when a point connected with the earth was presented to it.

From this effect of points on electrified bodies, Franklin inferred that lightning might also be drawn silently and safely from the clouds by a metallic point fixed at a great elevation, and he waited with considerable anxiety the completion of a spire at Philadelphia to enable him to try the experiment. In the meantime he published the results of his discoveries, and recommended that where opportunities occurred the trial should be made.

In a letter to Dr. Lining of Charlestown, containing answers to several questions, Dr. Franklin has given the following account of the origin of the idea that led to the grand discovery:—"Your question, how I came first to think of proposing the experiment of drawing down the lightning in order to ascertain its sameness with the electric fluid, I cannot better answer than by giving you an extract from the minutes I used to keep of the experiments I made, with memorandums of such as I purposed to make, the reasons for making them, and the observations that *arose upon them*, from which minutes my letters were afterwards

drawn. By this extract you will see that the thought was not so much an 'out-of-the-way one,' but that it might have occurred to an electrician. 'Nov. 7, 1749. Electric fluid agrees with lightning in these particulars: 1. giving light; 2. colour of the light; 3. crooked direction; 4. swift motion; 5. being conducted by metals; 6. crack or noise in exploding; 7. subsisting in water or ice; 8. rending bodies it passes through; 9. destroying animals; 10. melting metals; 11. firing inflammable substances; 12. sulphureous smell. The electric fluid is attracted by points. We do not know whether this property is in lightning, but since they agree in all the particulars in which we can already compare them, is it not probable they agree likewise in this? Let the experiment be made."

Acting on this suggestion, two Frenchmen, M. Dalibard and M. Delor, separately erected apparatus for the purpose of collecting electricity from the clouds; the former at Marly la Ville, about six leagues from Paris, the latter at his residence situated on high ground in Paris itself. M. Dalibard's apparatus consisted of an iron pointed rod forty feet long, the lower end of which was inserted in a sentry-box protected from rain, and on the outside it was fastened to three wooden posts by silk cords also defended from the rain. It was this rod that first attracted electricity from the clouds. M. Dalibard was absent from Marly at the time, and had left the apparatus in charge of a joiner named Coiffier. On the 10th of May, 1752, between two and three o'clock in the afternoon, a sudden clap of thunder made Coiffier hurry to his post, and, according to the instructions given him, he presented a phial furnished with a brass wire to the rod, and immediately saw a bright spark accompanied by a loud snapping noise. After having taken another spark stronger than the first, he called in the neighbours, and sent for the Curé. The latter ran to the spot with all speed, and his parishioners seeing him running, followed at his heels, expecting that Coiffier had been killed by lightning; nor were they prevented from hastening to the spot, notwithstanding a violent hail-storm. The Curé was equally successful in drawing sparks from the iron rod, and instantly despatched an account of the important event to M. Dalibard. The Curé stated that the sparks were of a blue colour, an inch and a-half long, and smelt strongly of sulphur. He drew sparks at least six times in about four minutes, and in the course of these experiments he received a shock in the arm extending above the elbow, which he said left a mark such as might have been made by a blow with the wire on the naked skin.

Eight days after the identity of lightning and electricity had

been proved at Marly, the rod erected by M. Delor, which was ninety-nine feet high, yielded electric sparks; and the same phenomenon was afterwards exhibited to the French king and to numbers of the nobility.

In the meantime, Dr. Franklin remained at Philadelphia unconscious of the success which had attended the adoption in France of his suggestion for drawing lightning from the clouds. Becoming impatient to verify his opinion of the identity of lightning and electricity, it occurred to him that he might establish an electrical connection between a thunder-cloud and the earth by means of a boy's kite, without waiting for the completion of the spire. Accordingly, on the first promising occasion, which occurred in June, 1752, a month after the success at Marly, he undertook the experiment. Afraid of being laughed at should the expedient fail, he took his son with him to make it appear that he was merely going for the boy's gratification, to assist in flying the kite. The apparatus consisted of a silk handkerchief attached at the corners to two laths placed crosswise. The kite thus constructed was able to bear a shower of rain without being injured. A pointed wire was fixed to the top to attract the electricity, but there was no conducting substance in the string, which was made of common packthread. At the end of that imperfect conductor a key was attached to collect the electricity, and a piece of silk ribbon was fixed to the key to insulate it from the hand. When the kite was raised in the air Dr. Franklin held the ribbon and looked with great anxiety for the result.

Some thunder-clouds passed over the kite, but there was no sign of electricity. At length, as Franklin was about despairing of success, he perceived some fibres of the hempen string to stand erect and to avoid one another, just as they would have done if electrified. He then presented his knuckle to the key, and to his unutterable delight received a spark. Other sparks succeeded, even whilst the string was dry, and consequently a very imperfect conductor; and when the rain had wetted it, he drew forth sparks very copiously, with which he charged a Leyden jar.

Dr. Franklin afterwards erected an iron rod on the top of his own residence, and one end of the rod being conveyed into his study, he was able at his convenience to perform with lightning all the experiments of artificially-excited electricity. That his attention might be drawn to the apparatus whenever lightning was attracted, he attached a set of bells to the rod, which by the attraction of their clappers, gave the signal. Sometimes these bells rang so violently as to be heard all over the house.

The application made by Franklin of his great discovery to the protection of buildings from lightning, was the first practical benefit derived from the science of electricity. He inferred, as points are so efficacious in attracting lightning, that a pointed metallic rod attached to the side of a house, rising some height above it and descending to the earth, would draw the electricity from a passing thunder-cloud silently, and thus prevent a sudden discharge; or if a flash of lightning should strike the rod, that the electric fluid would be conducted safely through the metal to the ground. He consequently recommended the attachment of such protecting rods to all exposed buildings, and to the masts of ships. Experience has proved the correctness of his inference, and the value of the suggestion. The plan has been extensively adopted, and has been the means of protecting every building and ship to which such conductors have been properly applied.

Electricians in all parts of the world were anxious to repeat the experiment of drawing electricity from the clouds. In doing so many of them received injuries and had narrow escapes from being killed, in consequence of the hazardous manner in which they performed their experiments. No one succeeded in attracting such large and continuous torrents of electric fire as M. de Romas of Nerac, who employed an electrical kite in the string of which a thin wire was inserted, to serve as a better conductor than the hempen string alone. The kite he used was seven feet high and three feet wide, and a tin tube connected with the wire-string was sustained at a short distance from the ground by means of a silk ribbon, which served when the kite was elevated, to insulate the wire from the operator. In experimenting with this kite, when raised to a height of 600 feet, in August, 1756, the streams of fire issuing from the tin tube were represented to have been one inch thick, and ten feet long; and on one occasion a loud explosion was heard and a flash of lightning passed from the tin tube to the earth, making a small hole in the ground. At such times when the flow of electricity was very abundant, M. de Romas experienced the same sensation over his face as is produced by the prime conductor of an excited electrical machine, which induced him to retreat and discontinue the experiments, from the dread of receiving a shock. Experience had taught him caution; for when he first raised his kite, and whilst taking hold of the wire-string, he was struck severely. M. Mormier, a member of the Academy of Sciences, and M. Bertier of Montmorency, were both knocked down by flashes of lightning, whilst taking sparks from their apparatus; and numerous other persons were more or less injured.

A fatal warning of the danger of experiments with lightning

... the death of Professor Richmann of St. Peters- ... 26th of August, 1753. He had constructed an ... which he called an *electrical gnomon*, to measure the ... electricity, and was observing the effect of a thunder- ... his instrument, accompanied by M. Solokow, an ... Professor Richmann was standing with his head ... towards the gnomon, when M. Solokow, who was close to ... saw, as he expressed it, "a globe of blue fire as large as ... from the rod of the gnomon towards the Professor's ... which was about a foot distant. This flash caused the ... death of the Professor, and M. Solokow was so ... that he could give no distinct account of the ... himself. He said that there arose a sort of steam ... which entirely benumbed him, and made him sink ... the ground, so that he could not even hear the ... clap of thunder, which was very loud. The ... the lightning were very apparent in the room; the ... was split through, and the door torn off its hinges and ...

... Professor Richmann's body, a red spot was ... the forehead, from which some drops of blood issued ... though the skin was not broken. The shoe ... was burst open, and a blue mark was found on ... the foot; from which appearances it was assumed ... entered the head and passed through the ... The body itself exhibited several red and blue ... the exception of the left shoe, the dress was unin- ... the body was opened, twenty-four hours after ... was without injury, and the brain perfectly ... parent pellicles of the windpipe were ex- ... were easily rent. There was some extra- ... cavities below the lungs; and the throat, ... entrails were all inflamed. The body so ... that two days after death it could with ... the coffin.

... of lightning is exactly the same as that ... jar or electrical battery. The author ... personal experience on this matter, though ... was too slight to produce any dis- ... During a severe thunder-storm, accom- ... he was endeavouring to prevent the ... stopping up the conduit-pipe, when an ... through his right arm, from the wrist that ... pipe to the elbow that rested on the ... very startling, an ... duced him to

make a quick retreat. A loud clap of thunder immediately followed, indicating that a powerful flash of lightning had struck the house; but several metal pipes conducted it safely to the ground, and it was so divided by passing through those conductors that but a very small portion of the discharge could have passed through the imperfect connection formed by the author's arm.

One of the first objects of scientific experiments on lightning was to determine whether the electricity from the clouds was positive or negative. Franklin found, during his experiments in the spring of 1753, that the lightning-rod exhibited in every case signs of negative electricity; he therefore concluded, somewhat too hastily, that the clouds are always negatively electrified, and that during thunder-storms it is the earth that strikes into the clouds, and not the clouds into the earth. In a subsequent experiment, however, he found the electricity positive. The observations of other electricians serve to show that the electrical condition of the clouds frequently varies from negative to positive, and that these changes occur during the course of the same storm.

The pointed rod with the accompanying apparatus to detect when a thunder-cloud was passing, were soon found to indicate the presence of electricity, not only when there was no thunder-storm, but when the atmosphere was perfectly clear. Signor Beccaria especially made searching investigations into the subject, and determined the close connection between electricity and all meteorological phenomena; nor has much been done in elucidating this mysterious connection since the researches of that distinguished philosopher.

The discovery of the identity of lightning and electricity may be considered as the culminating point in the history of electricity during the last century. No very striking discoveries resulted from the researches of the many electricians who were engaged in investigating the new field opened to their researches; nevertheless, numerous interesting facts were made known, and considerable light was thrown on the laws that govern the actions of the electric fluid.

The discovery, for instance, by Mr. Canton of the property of electrical induction, though not of a character to produce any marked impression at the time, has proved of the utmost consequence in explaining the phenomena of electricity. In the earlier years of the science an obscure notion was entertained of the influence of excited electrics in bodies at a distance from them; but *nothing* was *actually* known of this influence until *Mr. Canton proved, by* numerous experiments, that an excited

electric always induces in other bodies within the sphere of its influence an electrical condition of a kind different from that itself possesses. Mr. Canton found that when he brought an insulated conducting body near to an excited electric, it became electrified so long as it remained there, and that if the electric were positive that part of the conducting body nearest to it would be negatively electrical, and the more distant part would exhibit positive electricity. This sympathetic state of electricity, he ascertained, continued only whilst in the vicinity of the excited electric, and that the insulated conducting body on being removed, returned to its natural state. If, however, whilst under the electrical influence, the part farthest from the electric was touched by a conductor, so as to enable it to throw off the electricity repelled to that end, the body remained in an electrical state after the excited electric was removed. These remarkable phenomena were ascribed by Mr. Canton, and also by Dr. Franklin, who verified the experiments, to the presence of electrical atmospheres round all bodies, which atmospheres were supposed to be mutually repellent.

M. Æpinus and Mr. Wilcke, who experimented together with a view to elucidate the cause of the inductive property of electricity, were led to infer that the repelling power exerted at a distance by excited electrics would enable them to charge a space of air included between two conducting plates, in the same manner as a plate of glass is charged when coated on both sides with tin foil. The experiment answered their expectations, and succeeded at a distance of several inches between two insulated metal discs supported horizontally. When a discharging-rod was connected with the upper and lower plates, a loud discharge, like that of a Leyden jar, instantly took place.

It may be observed that the property of induction might have been deduced from the action of the Leyden jar, as explained by Franklin, for one side of the glass was proved by him to be in the opposite condition of electricity to the other. But until the experiments of Mr. Canton it could not have been inferred that positive electricity would operate at a distance in communicating negative electricity through the non-conducting air.

Mr. Canton also advanced the progress of electrical science by ascertaining that the kind of electricity excited by the friction of any given substance may be changed from positive to negative, or the reverse, by using different rubbers, or by altering the surfaces of the electrics. Glass is less susceptible of these changes than other electrics, but its generally positive state may be converted into negative by employing the back of a cat for the rubber, or by roughening the surface. To Mr. Canton is

further due the merit of introducing the application of a metallic amalgam to the rubber, to facilitate the excitement of electricity.

The opinion which for some time after the exposition of Franklin's theory had been generally entertained, that electrical phenomena depended on the disturbance of the equilibrium of one electric fluid, was very ably disputed by Mr. Symmers in a communication to the Royal Society in the year 1759. He adduced several experiments which he considered could only be properly explained on the supposition of the existence of two electric fluids, not indeed independent, but, on the contrary, always co-existent and counteracting each other. This theory closely resembled that of Du Fay, and the old terms of vitreous and resinous electricity were adopted by Mr. Symmers; Du Fay, however, originally conceived, in opposition to all observed electrical facts, that the two electricities were independent of each other, and were never combined.

The revival of the theory of vitreous and resinous electricity by Mr. Symmers deserves to be specially noticed in this place, for though it did not receive much attention at the time, it formed the foundation of the opinion now generally entertained by electricians on the Continent, where the theory of two distinct electric fluids has in a great measure supplanted the more simple *plus* and *minus* theory of Franklin. A very impartial review of the experiments of Mr. Symmers, and of the inferences founded on them, is given by Dr. Priestley,* who, though an advocate of the Franklinian theory, admitted that all the phenomena of electricity might be equally well explained by the supposition of the existence of two distinct fluids as of only one, and that as regards repulsion, the explanation was even more satisfactory. Dr. Priestley, however, adhered to the single fluid as the more simple theory, and as presenting closer analogy to what is known of the operations of nature in other branches of science.

M. Æpinus and the Hon. Henry Cavendish brought mathematical science to bear on the phenomena of electricity, and thus determined some of the laws that govern its attractive and repellent forces. These researches were pursued still more successfully by M. Coulomb in 1785 with the aid of the electrometer he invented, called the torsion balance, for measuring the force of electrical attraction and repulsion. In that instrument a filament of silk or spun glass serves to suspend horizontally a fine needle of shellac, with a small gilt pith ball

* *History of Electricity*, p. 247.

fixed at one end. A small ball charged with electricity is then brought near the suspended pith ball, when the latter is repelled and the suspending filament receives a twist occasioned by the mutual repulsion of the two balls. Whilst they are thus repelled they are forced together by means of a screw to which the filament of glass is attached, and the degree of torsion or twist produced in the filament by forcing the two balls together is measured by an index. The delicacy of the instrument is so great that a force not exceeding the 20,000,000th part of a grain may be indicated.

With this sensitive indicator of electrical forces, Coulomb deduced the following important laws which govern the electric fluid :—That bodies electrified by similar electricities repel each other with a force that diminishes in the same proportion as the square of the distance between them is increased; and that the mutual attraction or repulsion of two electrified bodies is directly proportional to the quantity of electricity with which they are charged, and diversely proportional to the square of the distance between them. Coulomb ascertained that electrified bodies, when insulated, gradually lose their electricity by the conduction of the surrounding atmosphere, which is never free from moisture, and by the imperfect insulation afforded even by the best electrics. He also determined in a more decided manner than had previously been done, that frictional electricity is accumulated only on the surfaces of conducting bodies, and does not penetrate the interior.

A few years before the invention of the torsion balance, the electrophorus of M. Volta had been added to the apparatus of the electrician. This instrument is principally valuable as exemplifying in a remarkably striking manner the action of induced electricity. When an insulated metal plate is brought into contact with a cake of rosin, or with any other flat electric surface when excited, the insulated plate is immediately rendered electrical; but not, as might be supposed, by electricity communicated directly from the rosin, but by induction. The two sides of the metal disc become in opposite states of electricity; that side nearest to the electric being charged with the contrary kind to that of the electric itself. Supposing a cake of rosin to be employed, the metal surface in contact with it is positively electrified, and the other side negatively. If when thus in contact, the finger, or any other conducting body, be brought near the plate, the negative electricity passes off in a spark, and the plate being then lifted up by the insulating handle, it will be found to be electrified positively; and so strongly, that sparks nearly an inch long may be taken from it. In this manner, by a succession of contacts electricity may

be developed sufficient to charge several Leyden jars without sensibly diminishing the electricity of the excited rosin.

The principal remaining incidents in the progress of electric science to the end of the eighteenth century were the results of the researches of Lavoisier, La Place, and others relative to electrical excitement by the evaporation of fluids, and by the solution of solids in acid menstrua. In every instance of sudden change of state, and of rapid chemical action under such circumstances, electricity was developed. These experiments by the French chemists indicated the close connection between electricity and chemical action, which subsequent investigations have proved to possess a most important bearing on the development of electricity.

CHAPTER III.

Discovery of Galvanism, and the circumstances that led to it—Galvani's erroneous notions of the exciting cause—Volta's investigations—Invention of the Voltaic pile—Commencement of the science of Voltaic electricity—Various Voltaic batteries—Theories of their action—Investigations by Sir Humphrey Davy—Decomposition of the alkalies and earths—The experiments that led to the discovery founded on a hoax—Prodigious Voltaic batteries constructed—Napoleon Bonaparte's experience of their power—Unsuccessful application of Voltaic electricity by Sir H. Davy.

As the last century drew to its close, a new era commenced in electric science of far more importance to its development than any of the preceding stages of advancement. The first glimmering of light in the new direction, as in most of the preceding discoveries, arose from fortuitous circumstances; and it is worthy of notice that this discovery also was founded on ignorance of the principle on which it depended.

Galvani, an anatomical professor at Pavia, has the merit of being the originator of that branch of electric science which was for many years termed *galvanism.* One account of the discovery represents that his attention was first directed to the subject by his wife and a pupil, who had observed the limb of a frog convulsed when touched by a knife near to an electrical machine. Madame Galvani is made more conspicuous in the matter by the assertion that she was an invalid, and that the frogs had been procured as delicate morsels for her dinner. It is stated, however, by Galvani, in a work published at Bologna in 1791 for the Institute of Sciences,* that he was dissecting a frog on a table whereon stood an electrical machine, when the limbs suddenly became convulsed by one of his pupils touching the crural nerve with a dissecting-knife. This occurred at the instant that a spark was taken from the conductor of the machine. The experiment was repeated several times, and it was found to answer in all cases when a metal conductor was connected with the nerve, but not otherwise. Galvani, who entertained the opinion that muscular action is attributable to electricity, looked on this phenomenon as a confirmation of that opinion, and pursued the inquiry with great zeal. Having tried various experiments successfully with the electrical machine, the electro-

* *Aloysii Galvani* de viribus electricitatis in motu musc[illegible] [illegible]mentarius.

phorus, and other artificial kinds of apparatus, he also tried the effect of atmospherical electricity. He attached the legs of frogs to a pointed conductor fixed at the top of the house, and found that they were violently convulsed by every flash of lightning. Similar effects, though not so strong, were also produced by atmospherical electricity, when there was no thunder-storm. In the prosecution of these researches, he suspended some frogs on metal hooks from the iron railings of his garden, and observed the contractions in all states of the weather, when he connected the hook with the iron rails. He therefore supposed that the effect might be produced independently of the atmosphere; and he found, on experimenting with a frog in his room, that whenever a metallic connection was made between the external muscle and the crural nerve, the limbs became convulsed. As this effect was produced without any apparent external excitement of the electric fluid, Galvani inferred, in accordance with his preconceived hypothesis, that the muscular contraction was caused by animal electricity; that the muscle and the nerve were in the condition of the inside and the outside of a charged Leyden jar, and that the metallic connection merely served the same purpose as a discharging wire, by giving the two electricities the means of combining.

It has been observed, that had Galvani been more accustomed to electrical experiments, he would have paid no attention to the convulsion of the frog's limb, and would have considered it merely as the customary effect of electricity when passed through an animal conductor. The same fact had, indeed, been observed by others, and thus disregarded. But Galvani, impressed with his idea of muscular action being caused by animal electricity, brought the fact prominently forward. The electricians who had observed the same phenomenon without regard, formed, indeed, more correct notions of the cause than Galvani, but by his endeavour to establish an error, he was the means of elucidating a most important truth.

In the meantime, the extraordinary physiological effects produced by such insignificant means gave countenance to Galvani's notion that they were produced by animal electricity. Physiologists eagerly seized hold of this assigned cause of vital energy, and abandoned the agency of the "nervous fluid" for that of electricity. Volta, however, manfully combated the opinion that the exciting cause resided in the animal fibres, and contended that the muscular contractions produced when the muscle and the nerve were connected by a metal, arose from the contact of the metal itself, and was entirely independent of animal electricity. In support of this opinion was adduced the peculiar

sensation occasioned by the contact of a piece of silver with a piece of lead or zinc, when both are placed upon the tongue; a fact which had been noticed by M. Sulzer in 1762, without attracting much attention.* Volta conceived that by combining a series of silver and zinc plates, he should be able to add to the electrical effect as he should thus increase the number of metallic contacts. He therefore piled up a series of plates, consisting of zinc and silver alternately, with interposed pieces of wet cloth, and obtained the expected accumulation of electrical force.

The results of Volta's important experiments were announced in a letter to Sir Joseph Banks, which was read before the Royal Society on the 26th of June, 1800. In that communication M. Volta stated that he had obtained some striking results from electricity excited by the simple mutual contact of different kinds of metals, and even by the contact of other conductors different among themselves, whether liquid or containing some fluid to which they were indebted for their conducting properties. The principal results he stated were, "the construction of an apparatus which resembles, in its power of producing electric shocks and other electrical phenomena, the Leyden jar, and still more closely electrical batteries when feebly charged; which operate also without ceasing, and possess a perpetual impulsion."

This apparatus consisted of discs of silver and zinc, about one inch diameter, and small discs of card or parchment, moistened with water or with a solution of common salt. The metal discs were piled upon one another alternately, and between every two was applied one of the moistened cards. With a series of twenty of these pairs of discs, he stated that Cavallo's pith ball electrometer, aided by a condenser, was affected to the extent of from 10° to 15°; that when wires connected with the upper and lower plates of the series were brought together, sparks were emitted; and that the apparatus would give a shock through the fingers. With a series of fifty pairs, the shock, he stated, became so

* The following extract from M. Sulzer's writings marks the first dawn of this important discovery:—

"When two pieces of metal, one of lead and the other of silver, are so joined together that their edges make one surface, a certain sensation will be produced on applying it to the tongue, which comes near to the taste of martial vitriol; whereas each piece by itself betrays not the slightest trace of that taste. It is not improbable that, by a combination of the two metals, a solution of either of them may have taken place, in consequence of which the dissolved particles penetrate into the tongue; or we may conjecture that the combination of these metals occasions a trembling motion in their respective particles, which, exciting the nerves of the tongue, causes that peculiar sensation."—*Theory of Agreeable and Disagreeable Sensations; Berlin,* 1762.

powerful as to reach to the shoulders, and when passed through a single finger, the pain was too great to be borne.

Volta, it is probable, exaggerated the effects of this diminutive apparatus, and he evidently mistook the partial combustion of the metallic wires, on making contact, for the electric spark, which can only be produced by a much more numerous and more powerful arrangement than Volta employed.

Volta had been a long time in obtaining the results communicated in his letter to Sir Joseph Banks. Having experienced the inconvenience of the pile, he contrived an arrangement called by him *à couronne de tasses*, in which zinc and copper plates connected together by wires were immersed in different cups containing a solution of common salt. A series of these cups formed a very efficient battery, and he was enabled, as he said, to produce effects which, though considerably less active than a battery of Leyden jars, possessed nevertheless immense power. The close resemblance of the electricity evolved in this manner to that of the torpedo did not fail to strike Volta, who accordingly called his apparatus an artificial electrical organ (*organe électrique artificiel*).

The discoveries of Volta, though far surpassing in importance those of Galvani, were at first considered merely subservient to the purpose of giving greater effect to the experiments of the latter. The increased muscular energy that could thus be given to the limbs of recently killed animals excited amazement and awe, and itinerant lecturers in all parts of the kingdom exhibited these wonders to collected multitudes; nor were there charlatans wanting, who by tricks of legerdemain gave a still more marvellous appearance to the really extraordinary effects of this newly discovered agent. The importance of the exciting power thus became merged in the effects it produced, and because the battery of Volta was at first chiefly employed to illustrate the discovery of Galvani, it received the name of the "Galvanic battery." That name was for a long time retained, and the new branch of science founded upon it was still more unjustly termed Galvanism.

As the new mode of exciting electricity was announced in 1800, we may date from the beginning of the present century the commencement of the science of voltaic electricity. In the early days of this discovery it was not determined whether to consider it as a modification of the electric fluid, or as a distinct agent excited by the contact of metals, though the researches of the most eminent electricians have since established the identity of the two.

The points of resemblance between the two electricities are,

that both produce the same physiological effects, the shock being communicable by both through a great number of persons instantaneously; that the same substances are conductors and non-conductors of both kinds of electricity; that both possess the power of igniting and heating; that sparks are emitted by the voltaic battery when great numbers of plates are used to increase the intensity of the force: that the phenomena of attraction and repulsion are common to both, and by both chemical decomposition can be effected.

The differences between voltaic and frictional electricity consist in the continued duration of the effects of the former, and in the different states of intensity in which the two kinds of electricity are evolved: voltaic electricity being evolved in great quantity at a low degree of intensity, whilst the quantity of frictional electricity excited is comparatively very small, but at a high degree of intensity.

The different conditions in which the electricities of the voltaic pile and of the electrical machine are excited, occasion a difference in the phenomena of each. It was not, for example, an easy matter to make an arrangement with frictional electricity for the exhibition of chemical decomposition, and on the other hand the electric spark of the voltaic battery could not readily be made to force itself through even the smallest space of air. The experiments of Dr. Wollaston, of Sir Humphrey Davy, and more recently of Dr. Faraday, have, however, removed all doubts respecting the power of frictional electricity to effect chemical decomposition; and, on the other hand, Mr. Crosse, with a water battery of 2,000 cells, evolved voltaic electricity possessing sufficient tension to force itself in a rapid succession of sparks through an intervening space of air.

Numerous attempts were made soon after the announcement of Volta's discovery and invention to improve the form of the apparatus. These endeavours have been continued with more or less success to the present day, though the arrangement *à couronne de tasses*, modified and rendered more compact, is still that most frequently adopted. The only marked variations in the principle of construction which require to be noticed in this part of our work, were the increase of the quantity of electricity by enlarging the size of the plates, so as to communicate greater heating power to the battery, and the increased intensity produced by greatly adding to the number of combinations, as in the column of De Luc. The latter arrangement deserves notice also, from the circumstance that no moisture is applied to produce the effects. This apparatus, as improved by Zamboni, consists of discs of paper, on one side of which is pasted finely laminated

zinc, and the other side is covered with powdered black oxide of manganese. The paper so prepared is cut into discs about one inch in diameter, which are arranged over one another with the zinc sides placed in the same direction; and, after having been pressed together, they are enclosed within a glass tube. This instrument, when it consists of a pile of 10,000 discs, exhibits a constant excitement of electricity of considerable intensity. It deflects the gold leaves of the electrometer, yields small sparks, charges a Leyden jar, and attracts and repels light substances in the manner of an excited glass tube. Its action continues without intermission for months, and even for years. A pile consisting of 1,000 prepared paper discs may be arranged so as to keep a small pendulum vibrating between its opposite poles, and it thus approaches more closely than any other invention to perpetual motion.

The action of this instrument depends on the small quantity of moisture contained in the paper. The paper is interposed between the zinc and the manganese, in the same manner as the discs of cloth in a voltaic pile, and though apparently dry, it contains sufficient moisture in all states of the atmosphere to act as a conductor.

The exciting cause of electricity in the voltaic battery was conceived by Volta to be the contact of dissimilar metals. The liquid wherein the plates are immersed was regarded merely as the conductor of electricity from one pair to another, and the advantage of employing saline solutions in preference to water was attributed to their superior conducting power. This theory was quickly combated by Dr. Wollaston, who ascribed the effect entirely to the chemical action of the solution on the zinc. That opinion was afterwards ably confirmed by Sir Humphrey Davy, who proved by various experiments, that chemical action is essential to the excitement of voltaic electricity. He showed, also, that a voltaic battery may be constructed without any metallic element. In November, 1801, he formed a battery of this kind, which consisted of ten pieces of well-burnt charcoal, with nitric acid and water arranged alternately in wine-glasses, which produced all the effects usually obtained from an alternate arrangement of zinc, silver, and water. More recently, Dr. Faraday has shown, that when the usual elements are employed, voltaic action may be excited without contact of the metals. Notwithstanding these evidences of chemical action, the contact theory continues to be the favourite hypothesis with philosophers on the Continent, and the action of De Luc's column, without the perceptible presence of any fluid, has given countenance to that opinion.

Whether chemical action be, or be not, the exciting cause of voltaic electricity, the agency of the latter in disturbing chemical affinities is one of its most remarkable and important characteristics. Nor did this extraordinary power long lie dormant. Two months before Volta's communication was read before the Royal Society, Messrs. Nicholson and Carlisle effected the decomposition of water by Volta's apparatus, which had been described in foreign journals; and Sir Humphrey Davy, improving on those experiments, succeeded in producing the oxygen and hydrogen gases from separate portions of water, in different glasses, connected together by moistened threads. Following up these experiments, he decomposed several compound bodies, and in every case he found that when substances containing sulphur or metal combined with oxygen were operated on, the sulphur and metal appeared at the negative end of the battery, and oxygen at the positive end. He was led to infer from these and similar experiments on the decomposition of bodies with the voltaic battery, that electrical action is identical with chemical affinity.

In pursuing his investigations into the nature of the action of the voltaic battery, Sir Humphrey Davy ascertained that the intensity increases with the number of the plates, and that the quantity of electricity excited is dependent on their size; a fact which was subsequently verified by Mr. Children, who, with a single pair of very large plates of zinc and copper, was enabled readily to melt the most infusible metals.

Armed with such a powerful decomposing agent as the voltaic battery, numerous chemical experimentalists pursued their researches into the elementary constituents of bodies with great ardour. Dr. Henry decomposed several of the acids, and resolved ammonia into its proximate elements. Berzelius transferred the elements of neutral salts to their respective poles; the acids being collected at the copper end of the battery, and the alkalies and earths being attached to the zinc terminus. These and various other results were published in the journals, and served to give additional stimulus to electro-chemical investigations.

Whilst scientific men were anxiously looking for important results from the inquiries thus sedulously pursued, there appeared in the *Philosophical Journal* a letter signed E. Peel, of Cambridge, announcing that, in his experiments on the decomposition of water, he had invariably found the pure water with which he commenced operating impregnated with common salt. This announced generation of salt by the action of the voltaic battery excited a lively sensation amongst philosophers in most parts of *Europe*. *Some* applied themselves to verify the experiment,

whilst others speculated on the new light supposed to be thus thrown on the cause of the saltness of the sea. The announcement was, however, soon afterwards detected to be a hoax, there being no person of the name of Peel at Cambridge. In the meantime, while the concocter of this practical joke was probably enjoying its success, experimentalists had actually obtained the results which he had published as a wildly extravagant notion. It was ascertained that distilled water, after having been acted on for some time by a voltaic current, contained in every case an appreciable quantity of salt. This proved a most perplexing discovery. The apparent creation of matter by voltaic action was as difficult to account for, as in later days has been the apparent creation of living insects by the same agency. Sir Humphrey Davy entered ardently into the investigation, and after a continued series of carefully conducted experiments, he ascertained that the salt or earthy matter eliminated was extracted from the substance of the threads employed, or was owing to the partial decomposition of the glass vessels in which the experiments were conducted. The more careful he was in avoiding those sources of error, the water became more free from saline particles; and when fibres of pure asbestos were substituted for thread, and agate cups for glass, no trace of alkali or earthy matter was to be detected in the water.

It was in pursuing these researches that Sir Humphrey Davy was led into the course of experiments which terminated in his brilliant discovery of the metallic bases of the alkalies and earths. The circumstance that the origin of one of the most important discoveries may be traced to the senseless trick of an unknown individual, presents a remarkable feature among the curiosities of science, and affords ample food for reflection to the speculative philosopher on the elimination of valuable truths from falsehood and error.

It is not strictly within our province to notice the labours of chemical experimentalists; but the decomposition of the alkalies and earths exhibits such striking examples of the chemical power of voltaic electricity, that the discovery of their bases by its means may be fairly considered to belong to the history of the progress of electric science.

From the first announcement of the discovery of the voltaic battery, Sir Humphrey Davy foresaw the vast importance of its agency in chemical researches. In a note-book dated August 6th, 1800, he writes: "I cannot close this notice without feeling grateful to M. Volta, Mr. Nicholson, and Mr. Carlisle, *whose experience has placed* such a wonderful and important

instrument of analysis in my power."* In his first Bakerian lecture, six years afterwards, he expressed the hope that "the new mode of analysis may lead us to the discovery of the *true* elements of bodies, if the materials acted on be employed in a certain state of concentration, and the electricity be sufficiently exalted. For, if chemical union be of the nature which I have ventured to suppose, however strong the natural energies of the elements of the bodies may be, yet there is every probability of a limit to their strength; whereas the powers of our artificial instruments seem capable of indefinite increase."†

In conformity with the notion of counteracting chemical attraction by electrical agency, he instituted a series of experiments on potass, with a view to its decomposition; the compound nature of the alkalies having been for some time suspected. At first he experienced great difficulty in getting the electric current to act on the potass, which when in a solid state is a non-conductor of electricity, and when acted on in solution the water only was decomposed. The first successful results were obtained by employing fused potass; inflammable matter was then developed, which burst into flame the instant it was formed. The complete success of the investigation occurred on the 6th of October. The following brief account of the discovery is contained in a manuscript of a lecture delivered at the Royal Institution:—

"*Experiments.* Then a piece of potass, moistened, and to my great surprise I found metallic matter formed.

"Oct. 6th. This matter instantly burned when it *touched water*, swam on its surface, reproducing potass. In dry oxygen gas likewise it burnt into perfectly dry potass."‡

"The extreme delight which he felt when he first saw the metallic basis of potass," observes Sir Humphrey Davy's brother, "can only be conceived by those who are familiar with the operations of the laboratory, and the exciting nature of original research; who can enter into his previous views, and the analogies by which he was guided; and can comprehend the vast importance of the discovery in its various relations of chemical doctrine; and, perhaps, not least, who can appreciate the workings of a young mind with an avidity for knowledge and glory commensurate. I have been told that when he saw the minute globules of potassium burst through the crust of the potass, and take fire as they entered the atmosphere, he could not contain his joy—he actually danced about the room in

* *Memoirs of the Life of Sir Humphrey Davy, Bart.*, by John Davy, M.D.
† *Ibid.* ‡ Ibid.

ecstatic delight, and that some little time was required for him to compose himself sufficiently to continue the experiment."

The battery power employed by Sir Humphrey Davy in effecting this brilliant result consisted of a combination of twenty-four plates of copper and zinc twelve inches square, one hundred plates of six inches, and one hundred and fifty of four inches. As it is a peculiar property of the voltaic battery that the quantity of electricity transmitted by a series of plates is dependent on the size of the smallest plate of the series, it follows that the power thus brought to bear was equal to that of a battery of 274 pairs of plates of four inches square. The managers of the Royal Institution afterwards placed at his disposal a voltaic battery of 600 double plates four inches square: and a still larger battery, consisting of 2000 plates, was constructed by subscription for his use.

The important discoveries of Sir Humphrey Davy, by means of the voltaic battery, caused increased attention to be paid to that valuable agent in chemical analysis, and voltaic batteries were made on a larger scale than any that had previously been constructed. It is related that when Napoleon heard of the decomposition of the alkalies by an English philosopher, he angrily questioned the *savans* of the Paris Institute why the discovery had not been made in France. The excuse alleged was the want of a battery of sufficient power. He immediately commanded one to be made; and when completed he went to the Institute to see it. With his usual impetuosity, the Emperor seized hold of the wires, and before he could be checked by the attendant, applied them to his tongue. His imperial majesty was rendered nearly senseless by the shock; and as soon as he recovered from its effects, he walked out of the laboratory with as much composure as he could assume, not requiring further experiments to test the power of the battery; nor did he ever afterwards allude to the subject.*

With the powerful voltaic batteries that were then constructed, the course of investigation into the constituent parts of bodies was steadily pursued; and numerous compound substances yielded up their elements to the decomposing influence. Substances that had resisted the greatest heat of the furnace were readily fused, and even the diamond was burnt in the voltaic arc, and its chemical character was identified with carbon.

We must not omit to notice the attempt made during this period by Sir H. Davy to practically apply voltaic electricity for the prevention of the corrosion of the copper sheathing on ships.

* *Dr. Paris's Life of Sir Humphrey Davy.*

He had ascertained that when two metals in contact are immersed in a saline solution, an increased action takes place on one of the metals, whilst the action of the solution on the other is diminished. Copper, for example, undergoes corrosion in sea water; but when zinc is in contact with it the corrosion of the copper ceases. Sir H. Davy applied this principle to copper sheathing, by protecting it with strips of zinc. The experiment succeeded scientifically by preventing corrosion, but it practically failed; for the copper thus protected became covered with sea-weed and shell-fish, which do not adhere to the corroded surface. Sir H. Davy was deeply mortified at the failure of this experiment in a practical point of view; but it has led to the discovery of an alloy of copper that answers the purpose intended very successfully.

CHAPTER IV.

Discovery of Electro-Magnetism—Increase of the force by coils of wire—Electro-magnets—Tangential action of the force—Invention of the Galvanometer—Its application to telegraphic purposes—Discovery of Magneto-electricity—Magneto-electrical machines—Thermo-electricity—Faraday's experimental researches—Introduction of new terms—Daniell's constant battery—Discovery of the electro-type process—Development of electricity from high pressure steam—Present state of electric science.

Though the investigations, conducted with the powerful means at command, elucidated many interesting facts, no remarkable discovery occurred for several years; and Dr. Bostock, in his *History of Galvanism,* appears to have considered that discoveries by the agency of the voltaic battery had reached their end. His words are: "It may be conjectured that we have carried the power of the instrument to the utmost extent of which it admits; and it does not appear that we are at present in the way of making any important additions to our knowledge of its effects, or of obtaining any new light on the theory of its action." This was written in 1818; and in the next year a new light—almost as brilliant as any of the preceding flashes that had illumined its progress—was thrown on electric science by the discovery of electro-magnetism.

That a close relation subsisted between electricity and magnetism had been known from an early period of its history, and the identity of the two had formed a subject of discussion. Franklin and his contemporary electricians, for instance, had communicated magnetism to small bars of steel by the charge of an electrical battery; and the power of the electrical battery in destroying and reversing polarity was also known.

It may be mentioned, as an indication that the question of the probable identity of magnetism and electricity excited considerable attention, that in 1774 the Electoral Academy of Bavaria proposed as the subject of a prize essay: "Is there a real and physical analogy between electric and magnetic forces; and if such analogy exists, in what manner do these forces act on the animal body?" Though the prize was gained by a professor who maintained that the two powers were essentially distinct from each other, there were not wanting competitors who as strenuously maintained that the forces were the same,

though modified by special circumstances. The impression, indeed, of the identity of electricity and magnetism continued very strong; and it is remarkable that no well-conducted experiments were undertaken to ascertain more closely the relations between the two forces. We heard it stated by Faraday, in one of his lectures at the Royal Institution, that when he was first connected with that institution, Davy and Young were frequently making experiments with the view of establishing the identity of electricity and magnetism, but that being misled by preconceived theories of the action of the force, they adopted nearly every conceivable mode but the simple one of holding a balanced magnetic needle over a wire transmitting a voltaic current.

Professor Œrsted of Copenhagen, to whom the world is indebted for the discovery of this new and practically useful department of science, published a work in 1807, in which he described the analogies between magnetism and electricity, wherein there occurs the following remarkable passage: "In galvanic action the force is more latent than in electricity, and it is still more so in magnetism than in galvanism. It is necessary, therefore, to try whether electricity in its latent state will not affect the magnetic needle." It does not appear, however, that Œrsted actually tried the experiment indicated in his book; nor does any one else seem to have made the trial, though we now know that the question would have been determined by merely placing a magnetic needle over the wire that formed the circuit of a voltaic battery. It was not till 1819, twelve years after he had pointed out the way to others, that Œrsted followed the course he had indicated. By bringing a magnetic needle in the direction of a voltaic current, he ascertained that the conducting wire is itself magnetic. He found also that the nature of the conducting medium is immaterial to the result: that whether the voltaic circuit be completed through metals or through a fluid, the magnetic needle is equally affected; it being deflected in one direction when placed over the conductor, and in the opposite direction when under it.

The discovery was no sooner made known than all those who were engaged in scientific researches throughout Europe pursued the inquiry with diligence, and continually elicited additional facts, which bestowed increased importance on this correlative branch of electric science. Messrs. Ampère and Arago, of the French Academy of Sciences, having discovered that the direction of the magnetic force is tangential to the wire, they succeeded in multiplying the power by twisting the conducting wire into *a spiral coil.* In this manner the action of the voltaic current

is frequently repeated within a small area. By adopting this arrangement sufficient magnetic force was obtained to attract iron filings to the coil. It was in September of the same year that Professor Œrsted's discovery was known, M. Arago communicated to the French Academy that the electric current possesses the power of imparting magnetism to iron and steel; and Sir Humphrey Davy ascertained independently the same important fact, though somewhat later.

It was discovered that the coil of wire through which the voltaic current was transmitted in these experiments operated in all respects like a magnet; but that the action ceased instantaneously when the current was interrupted. The power of the coil was found to be greatly augmented by introducing a bar of iron within it, to which bar magnetic properties were instantly communicated; but if the iron were pure and soft, those properties ceased the moment that the electric circuit was broken. The nearer the whorls of the coil were brought together without touching, the effect was found to be more concentrated. To prevent the communication of the electricity laterally in the folds of the coil, the wire was insulated. Varnish was employed for this purpose in the first instance, and afterwards silk or cotton was wound round it, to avoid metallic contact; that slight degree of separation being sufficient to prevent the conduction of voltaic electricity.

The insulation of the wire, trifling as the improvement appears to be, afforded the means of increasing the power of electro-magnetism to a most astonishing degree. Not only could the wire of the coil be twisted close together, but it could be wound upon itself many folds in thickness, each additional layer of wire giving increased magnetic effect. In this manner electro-magnets could be formed with sufficient attractive power to lift upwards of a ton; yet this attraction, so far exceeding that of any artificial magnet that can be made by other means, ceases the instant that the connection is broken between the coil of wire surrounding it and the voltaic battery.

The multiplication of the force of an electric current by transmitting it through coils of insulated wire, developed in an extraordinary manner the effect of induction, which had been observed in transmitting an electric current through a wire of great length. It had been noticed that the spark and snap were much greater on breaking contact through a long wire, than it was when the current was passing through a short one. This anomalous fact was ascertained to be owing to the induction of a separate current in the long wire, which effect could be still more perfectly developed when a second wire was placed

parallel to the first with its two ends connected. By that arrangement the electric current was transferred from the wire, through which connection was made with the poles of the voltaic battery, to the other, through which no electricity whatever was directly transmitted. When the two ends of the second wire were brought together and separated at the same instant that contact was broken with the voltaic battery, a bright spark was observed at the point of separation, and scarcely any spark appeared between the points of the primary wire which transmitted the voltaic current. This *secondary current*, as it is called, was found to be greatly increased by coiling the second wire round the primary one in numerous convolutions. By employing great lengths of very fine covered wire coiled in this manner round the wire through which the voltaic current is passing, the most astonishing effects may be produced. The quantity of electricity excited by a single pair of plates, may by this means be converted into intensity electricity, which communicates violent shocks, and exhibits most of the phenomena of frictional electricity.

Professor Œrsted having ascertained that the electric current in passing through a conducting wire acts on the magnetic needle transversely in every position in which it can be placed, he inferred that the magnetic effect of the electric current is to induce a tendency to circular motion round the wire. M. Ampère entertained the same view. Dr. Faraday contrived an ingenious apparatus for showing not only the rotation of a magnet round a conducting wire, but the rotation of a conducting wire round a magnet. This seemed to confirm the previously announced theory of M. Ampère, that magnetism is induced by circular currents round the magnetized bodies; and it appeared also to introduce an anomaly in the action of moving forces, which are always exerted in straight lines. The apparent anomaly may probably be removed by resolving the circular motion, like that of all other bodies moving in curves, into the operation of two forces acting in different directions.

The communication of rotary motion by electro-magnetism, and the powerful attractive force called into action by electro-magnets, were considered to indicate a new and valuable source of motive power, that could be applied directly to the production of rotary motion. Numerous attempts were made to apply the power to useful purposes as a substitute for steam. The notion is not yet abandoned, though there have been hitherto no practical results that lead us to expect the object will be attained.

A most valuable instrument in conducting researches in

voltaic electricity was contrived shortly after the discovery of the magnetic influence of the voltaic battery, and depending on that influence for its action. The low state of tension of voltaic electricity prevents it from being appreciable by the ordinary electrometer, excepting when the intensity is increased by the combination of an extensive series of plates. An attempt was made by Mr. Pepys, in the very infancy of voltaic electricity, to obtain an indication of its force by increasing the sensibility of the gold leaf electrometer; and he so far succeeded that with a pile consisting of a series of eighty pairs of plates, he produced a very decided deflection of the gold leaves, but the instrument afforded no indication of electricity with a smaller number. *

The experiment that discovered electro-magnetism, at the same time pointed out the means of measuring its force. When the possibility of multiplying the effect by means of folds of insulated wire twisted into a spiral coil became known, that mode of concentrating the power was quickly made available for giving increased sensibility to the magnetic needle. In this manner instruments called galvanometers were constructed of such extreme sensitiveness as to detect very minute quantities of voltaic electricity.

The invention of the galvanometer suggested the application of that instrument to the purpose of communicating telegraphic signals. That plan has, after numerous improvements, attained such a degree of perfection, that by the varied deflections of two galvanometer-needles, communications are transmitted between places hundreds of miles asunder almost as quickly as they can be written down. The idea of employing electricity for telegraphic purposes was indeed by no means new. So far back as 1774 a plan was proposed of transmitting signals through wires by causing pith balls to be deflected when an electric discharge was made. Subsequently the decomposition of water and the discharge of frictional electricity through insulated wires, were made available for the purpose. It was in 1830 that M. Ampère suggested the application of deflected needles, and in 1837 Mr. Alexander of Edinburgh exhibited in London the first electric telegraph on that principle. The plan was, however, impracticable, as it required a separate magnetic needle and a separate insulated wire for each letter of the alphabet.

We shall not attempt at present to follow the course of telegraphic invention, which will be fully described when we come to treat of the practical applications of electricity. It is sufficient in this place to observe that since the application in 1837

* *Philosophical Journal*, June, 1801.

of M. Ampère's suggestion, there have been upwards of two hundred patents obtained for different modes of telegraphic correspondence, most of them based on the same principle and depending for their action on electro-magnetism. By employing electro-chemical agency communications may now be instantaneously transmitted with a single connecting wire ten times faster than any one can write, and methods have also been invented of printing messages and of copying writing instantaneously at distances three or four hundred miles apart.

In pursuing investigations into the phenomena of electricity, Dr. Faraday was led to infer that as a current of electricity induces magnetism, the magnetic force would induce electricity. Aided by the multiplying power of the coil, and by the sensitiveness of the galvanometer, he was enabled to prove the correctness of the inference, and to establish the foundation of the branch of electric science termed *magneto-electricity*. His experiments were conducted in the year 1831, and shortly produced important results.

The induction of electricity by magnetism was in the first instance shown by connecting a hollow coil of wire with a galvanometer, and then inserting within the coil a powerful steel magnet. Whilst the magnet remained in the coil, the galvanometer gave no indication; but on quickly withdrawing the magnet, the needle was instantly deflected. A similar temporary deflection was observed to take place when the magnet was quickly introduced; and in November of the same year Faraday derived still more complete evidence of induction by eliciting an electric spark. The effect produced by inserting and withdrawing the permanent magnet into and out of the coil of wire was found to be greatly augmented when an electro-magnet was substituted for a permanent steel one, in consequence of the greater facility of changing the magnetic condition of the coil. The instant that the iron was rendered magnetic, by making contact with the battery wires, the temporary transmission of electricity took place through the coil of wire which surrounded it; and by making and breaking contact with great rapidity, there was a continuous succession of electrical effects.

The electricity thus induced in the secondary current was ascertained to be of a high degree of intensity, and to pass in a contrary direction to that of the primary current. The phenomena became more marked when the length of wire in the coil of the secondary circuit was increased. By adding greatly to its length, a degree of intensity was obtained equal to that of a numerous series of plates of a voltaic battery, though the primary exciting cause which communicated magnetism to the iron was only a single pair.

By improved mechanical arrangements, the principle of electro-dynamic induction, brought to light by the experiments of Faraday, has been made to operate as a most powerful exciter of electricity. Magneto-electric machines have been constructed with permanent steel magnets, that possess the power of intense voltaic batteries, and closely imitate the effects of frictional electricity in its most accumulated state. The shocks given by these machines are so strong as to be insupportable. They emit vivid sparks, and operate as decomposing agents. The instrument is also capable of being arranged as an exciter of quantity-electricity in a comparatively lower state of intensity, so as to fuse wire, induce magnetism, and exhibit the other phenomena common to the voltaic electricity excited from a pair of plates of large size. This mode of exciting electricity, independently of the friction of electrics or of chemical action, seemed to present the advantage of procuring a powerful agent with comparatively little labour and no cost of materials; and attempts have been consequently made, with considerable success, to apply it to practical purposes, which we shall have subsequently to notice.

Though the world is indebted to Faraday for the development of the induction of electricity from steel magnets, the fact that electrical effects could be so elicited had been imperfectly discovered at the beginning of the present century; but it had then no results, and was soon forgotten. The only notice of that discovery which we have been able to find occurs in the *Monthly Magazine* for April, 1802, to this effect:—"Galvanism is at present a subject of occupation of all the German philosophers and chemists. At Vienna an important discovery has been announced—an *artificial magnet*, employed instead of Volta's pile, decomposes water equally well as that pile or the electrical machine, whence it has been concluded that the *electric*, *galvanic*, and *magnetic* fluids are the same." It is curious to observe how thus in the course of time discoveries and inventions that have passed away and been disregarded, because circumstances were not then suited to their development, are revived in later years either by accident or by original research and ingenuity, and become important elements in the advance of science and the progress of civilization. We may notice also, in the preceding announcement, that the fact of the correlative nature of the three forces, which has been established by the persevering investigations of modern philosophers, was anticipated fifty years ago.

For the purpose of not breaking in upon the outline of the progress of electro-magnetism, we have passed by other discoveries of considerable importance to which it is necessary to revert.

An additional source of electricity was developed, in the year following the discovery of electro-magnetism, by Dr. Seesbeck, who communicated to the Academy of Berlin that he had succeeded in exciting electricity by the disturbance of temperature. He ascertained that two metals—antimony and bismuth being the most effective—when soldered together at their extremities and then heated at the junctions, whilst the other ends are kept cool, produce a decided deflection of the galvanometer. This property of the metals has no reference to their efficiency in voltaic arrangements, nor to their powers of conducting electricity. The effects first produced by Dr. Seesbeck were derived from the combination of four bars of antimony and bismuth in the form of a rectangular frame, one corner of which was heated and the other covered with ice.

Messrs. Nobili and Meloni succeeded in constructing thermo-electric piles by the combination of a series of bars of metal soldered together. With this apparatus most of the ordinary electrical phenomena have been produced, including the appearance of the electric spark, the decomposition of water, and the communication of magnetic properties. The quantity of electricity evolved by this means is, however, very small, and thermo-electricity has yet assumed little importance. Some philosophers, however, are inclined to attribute to the action of this power the hitherto unexplained effect of the magnetism of the earth. Thermo-electric currents are supposed by them to circulate round the globe with the heating rays of the sun, and thus to [illegible] magnetism at the poles.

Long previous to the discovery of Dr. Seesbeck, the influence of heat in exciting electricity had been ascertained, though the knowledge was then limited to its effects on crystalline bodies. [illegible] M. Lemery exhibited to the French Academy of [illegible] a stone, supposed to be tourmalin, which, when heated, [illegible] light substances; and the Duke de Noya performed [illegible] experiments with that crystalline body; but it [illegible] who first showed that heat or friction was necessary to produce the phenomena. The Abbé Haüy, celebrated [illegible] in crystallography, found that the electricity [illegible] decreased rapidly from the poles of the crystal, [illegible] when broken, each fragment is electrical, and is in a [illegible] condition. He afterwards discovered that topaz [illegible] crystals of similar conformation exhibit signs of [illegible] when heated. Sir David Brewster has more recently [illegible] the same property extends also to the crystals of [illegible]

[illegible] bodies which could thus be acted on by heat

were called pyro-electrical. As their phenomena depend on the same exciting cause as that which produces electricity in variably expansive metals, they may be considered as belonging to thermo-electricity; and we have deferred noticing them till they could be classed together with the crystalline metals that become electrical by heat.

Professor Faraday commenced in 1832 a series of experimental researches into the nature of electro-chemical action, the results of which were published from time to time in the *Philosophical Transactions*, and constitute most valuable contributions to electric science. One important point which these researches tend to prove is, that in the course of electro-chemical decomposition the elementary atoms of the compound substance acted on are transferred from atom to atom of the fluid, in a continuous chain from one pole of the battery to the other. The conduction of voltaic electricity through fluids is thus considered to be dependent on a successive series of decompositions and recompositions in opposite directions. Another important point which these researches may be considered to have established is, the law of definite electro-chemical action;—that "for a constant quantity of electricity, whatever the decomposing conductor may be, whether water, saline solutions, acids, fused bodies, &c., the amount of electro-chemical action is also a constant quantity, *i. e.*, would always be equivalent to a standard chemical effect founded upon ordinary chemical affinity."*

According to the views of Professor Faraday, electro-chemical decomposition is occasioned by "an internal corpuscular action excited according to the direction of the electric current; and that it is due to a force either superadded to or giving direction to the ordinary chemical affinity of the bodies present." He conceives, therefore, the effects of the decomposition "to arise from forces which are *internal* relative to the matter under decomposition—and not *external*, as they might be considered if directly dependent upon the poles."

To express these views of the action and direction of the forces exerted during electro-chemical decomposition, Faraday conceived that the terms previously employed were insufficient; he therefore determined to introduce a nomenclature suitable to the modes of action indicated. He obtained the assistance of two classical friends to aid him in this undertaking, and the result was the application of several Greek terms to denote processes and things which had been long known by other names. It may seem presumptuous to question the propriety of the

* *Experimental Researches in Electricity*, ¶ 505.

course adopted by that eminent philosopher, but so strong is our impression of the injurious effects of multiplying terms, requiring constant explanation, that we venture to express our conviction that it has tended unnecessarily to encumber the study of electricity.

The nomenclature of every science ought, in our opinion, to be extremely simple, and if possible, clearly expressive of the character or action of the thing or process designated; nor do we perceive any equivalent advantage gained by the adoption of the words of a dead language, which often serve no better purpose than to conceal by their unfamiliar sounds absurd, puerile, or questionable designations.

The terms previously in use to express the different electrical phenomena and conditions were so various as to afford ample choice to those who entertain differing views of the nature and actions of the electric fluid. There were "*plus* and *minus*," "positive and negative," "vitreous and resinous," to express the kinds of electricity excited;—and "electrics," "ideo-electrics," "non-electrics," "conductors," and "non-conductors," to indicate the electrical qualities of different substances. When voltaic electricity gave rise to new terms, the copper or zinc "end" of the battery was an intelligible English expression to denote what those more fond of classic names called "terminal," and which afterwards received the name of "pole." Possessed of this abundance of expressions, we do not conceive that any good purpose is answered by adding to the list a number of Greek words and terminations to express supposed analogies in the action of the voltaic battery. Faraday himself had evidently misgivings on the subject; for after explaining the meaning of the new terms, he adds: "I do not mean to press them into service more frequently than will be required; for I am fully aware that names are one thing, and science another;" and he afterwards found it advisable to change some of the terms for "such as were at the same time simple in their nature, clear in their reference, and free from hypothesis."* It is to be wished that he had from the first acted on his own judgment and knowledge, without being guided by his learned friends.

As it is our intention to present a clear and intelligible view of the science of electricity free from unnecessary technicality, we shall endeavour to avoid using any portion of the nomenclature constructed by Professor Faraday's philological friends; but as these terms will be often met with in other

* *Experimental Researches in Electricity*, vol. i., ¶ 666.

works on the subject, they must not be passed by unnoticed. We therefore adopt the following abbreviated explanation by Dr. Noad:*—

"What are called the *poles* of the voltaic battery are merely the surfaces or doors by which the electricity enters into or passes out of the substance suffering decomposition; Faraday hence proposes for them *electrodes*, from ἤλεκτρον and ὁδὸς, *a way*, meaning thereby the substance or surface, whether of air, water, metal, or any other substance, which serves to convey an electric current into and from the decomposing matter, and which bounds its extent in that direction.

"The surfaces at which the electric current enters and leaves a decomposing body he calls the *anode* and *cathode*, from ἀνα, *upwards*, and ὁδὸς, *a way—the way which the sun rises*; and κατὰ, *downwards*, and ὁδὸς, *a way—the way which the sun sets*. The idea being taken from the earth, the magnetism of which is supposed to be due to electric currents passing round it in a constant direction from *east* to *west*."—"The anode is, therefore, that substance at which the electric current enters; it is the *negative* extremity of the decomposing body; is where oxygen, chlorine, acids, &c., are evolved, and is against or opposite the positive electrode. The *cathode* is that surface at which the current leaves the decomposing body; the combustible bodies, metals, alkalies, and bases are evolved there, and it is in contact with the negative electrode."—"Compounds directly decomposable by the electric current are called *electrolytes*, from ἤλεκτρον and λύω, *to set free*—to *electrolyze* a body is to decompose it electro-chemically: the elements of an electrolyte are called *iöns*, from ἰὼν, participle of the verb εἶμι, *to go*; *anions* are the iöns which make their appearance at the anode, and *cations* are the iöns which make their appearance at the cathode, and were termed the electro-positive elements."—"Mr. Daniell proposes further to distinguish the doors by which the current enters and departs by the terms *zincode* and *platinode*; the former being the plate which occupies the position of the generating plate in the battery, and the latter of the conducting plate."

We have abstained from noticing the many alterations and improvements in the form and construction of the voltaic battery that have been introduced since the original discovery by Volta, partly because those which are of practical importance will be afterwards described, and partly also because such improvements are not of a character to produce any notable impression on the course of electrical discovery. The "constant" battery of Professor Daniell, however, invented in 1832, requires to be noticed

* *Lectures on Electricity.*

in this place; not only from the distinguishing principles of its action, but from its influence on the discovery of the process of electro-metallurgy.

In the arrangement *à couronne de tasses* of Volta, and in all subsequent contrivances for exciting voltaic electricity, the action of the battery diminishes rapidly after the first minute. This is attributable to the combined causes of the collection of bubbles of hydrogen gas on the conducting plate, and the deposition of the oxide of zinc. Professor Daniell, with a view to remove these obstructive effects, separated the fluid in which the zinc plate was immersed from that of the copper by an animal membrane, the interposition of which did not retard the passage of the electricity, whilst it effectually prevented the deposition of zinc on the copper plate. The collection of bubbles of hydrogen gas on the latter still, however, operated against the perfect action of the battery. To remove this impediment, the copper plate was immersed in a saturated solution of the sulphate of copper, which was kept separate from the acidulated solution surrounding the zinc plate by the animal membrane. By this arrangement the evolution of hydrogen gas was altogether prevented; for as quickly as detached from its combination with the oxygen of the fluid menstruum by the chemical action on the zinc surface, it seized on the oxygen of the metallic salt, and the metal before held in solution was deposited on the copper plate of the battery. Both of the previously existing causes of the diminution of the force of the battery were thus removed, and by keeping the solution in a saturated state, the action of the voltaic battery was steadily sustained. This "constant battery" of Professor Daniell has proved a valuable aid in prosecuting researches and in conducting processess that require the continuance of voltaic action for several days with the same amount of force.

The deposition of pure metallic copper from the solution of the sulphate, and the increase in weight of the conducting-plate by the aggregation of particles of copper, could not fail to be observed from the earliest use of the constant battery; and Professor Daniell noticed that on the removal of some portion of the deposited copper, the parts detached presented exact copies of the irregularities of the surface of the plate. Mr. De La Rue, who indeed preceded Professor Daniell in the use of a solution of sulphate of copper as the exciting fluid of an ordinary battery, sent a communication to the *Philosophical Magazine*, published in December, 1836, in which he mentions particularly the remarkable appearance of the deposited copper: "So perfect," he observes, "is the sheet of copper thus formed, that on being stripped off, it has the polish and even a counterpart of every scratch of the plate on which it was deposited."

We perceive, therefore, how closely Mr. De La Rue had arrived at the discovery of the electrotype process. It was, in fact, the process itself; conducted, however, without appreciation of its value, and without any idea of its practical application.

In the earliest period of the history of voltaic electricity, indeed, we find that Mr. Cruickshanks had observed that metals were "revived" from their solutions at the negative pole of the battery; and in 1805 M. Brugnotelli stated that he had "gilt in a complete manner two large silver medals, by bringing them, by means of a steel wire, into communication with the negative pole of a voltaic pile, and keeping them immersed in ammoniuret of gold, newly made and well saturated." It was not, however, till 1839 that any practical application was made of the deposition of metals from their solutions. There are three competitors for the honour of the priority of invention; but each one has the merit of having originated it about the same time independently of the others. M. Jacobi of St. Petersburg asserts that he discovered the process in February, 1837; but the first notice of his experiments made known in this country was published in the *Athenæum* of May 4, 1839. In 1837, Mr. Spencer of Liverpool had obtained a counterpart of the head and letters reversed of a penny-piece, which he had fortuitously used as a conducting-plate in his battery; and on the week following the publication of the notice of M. Jacobi's experiments, Mr. Spencer gave notice that he should read a paper at the Liverpool Polytechnic Institution containing the results of his experiments on the same subject; but the reading of it was deferred till September. In the meantime, a letter in the *Mechanics' Magazine*, from Mr. Jordan, a printer, gave a full and accurate description of the process. It, however, attracted no attention; and the matter dropped until Mr. Spencer's paper was read in Liverpool, illustrated with various specimens of electrotypes.

The first efforts with the electrotype process in this country were limited to obtaining fac-similes of coins and medals in imitation of the specimens shown by Mr. Spencer. The art of electro-metallurgy has since been largely developed, and it is still advancing into new fields of action. Among other applications it has been endeavoured to employ it as a substitute for manual labour in the fabrication of all kinds of copper vessels; but we believe the operation was found more costly than the ordinary mode of manufacture.

Electro-chemical metallic deposits have been successf
plied to coating natural objects with a film of meta

transference and multiplication of elaborately engraved plates, and even the delicate pictures of the Daguerreotype have been solidified by this means. But the most extensively useful application of the process has been to silver plating and to gilding. Electro-plating has been carried to a high state of perfection, and in many respects it possesses considerable advantages over the old modes of operating. Electro-metallurgy is yet, however, in its infancy; and though the experiment of fabricating metallic vessels by means of electro-chemical deposition has hitherto failed as a commercial undertaking, it is not improbable that further improvements—especially the discovery of some cheaper means of exciting electricity for practical purposes—may eventually render it an important branch of manufacturing industry.*

X A new and very unexpected source of electricity was discovered in 1840 in effluent high pressure steam. The discovery arose accidentally, owing to the issue of steam from a fissure in the boiler of a steam engine at Sedghill, near Newcastle. The engineer happened to have one hand in the issuing steam, whilst he touched the lever of the valve with the other, and was surprised to see a bright spark, accompanied by an electric shock. The same effect was produced whatever part of the boiler he touched, provided one hand was in the effluent steam.

Mr. Armstrong, to whom the fact was communicated, instituted several experiments with a view to develop the phenomena and ascertain their cause. He obtained sparks four inches in length from the issuing steam, by holding in it a bundle of wires, insulated by a glass rod, or held by a person standing on a glass stool. When the boiler was insulated and sparks were taken directly from it during the issue of the steam, the effects were still more powerful. The electricity of the boiler when so placed was generally found to be negative, and that of the steam positive.

One of the extraordinary features of this discovery was the great intensity combined with quantity of the electricity evolved. Mr. Armstrong in his experiments with a locomotive boiler produced effects upwards of seven times greater than those from a plate-machine three feet in diameter, working at the rate of seventy revolutions in a minute; and the apparatus at the Polytechnic Institution, which was constructed purposely for the evolution of electricity from high pressure steam, produces much more powerful effects.

* *See Napier's **Manual of Electro-Metallurgy**.* Third edition.

The cause of the development of electricity by this means was at first considered to be owing to the increased capacity of steam for the electric fluid when in its expanded state than when compressed within the boiler; and the phenomenon of the excitement of so large an amount of electricity by change of state was thought to afford a satisfactory illustration of the generation of atmospheric electricity. This explanation was so simple, and appeared so completely in accordance with the Franklinian theory of electrical excitement, that it seemed to command belief; and we must admit it was with considerable reluctance we felt compelled to abandon it. Professor Faraday undertook to investigate the question; and by a long series of well-devised and carefully conducted experiments, he appears to have proved very conclusively, that in the evolution of electricity the steam acts only a secondary part; and that the immediate cause of the electrical excitement is the friction of particles of water against the sides of the jet whence the steam issues. In pursuing the experiments with compressed air and gases, as substitutes for compressed steam, the same results were obtained when the tubes and jets contained moisture; but no electricity was apparent when the air and gases were dry.

An apparatus on a small scale for experimenting on the electricity evolved by effluent steam is one of the wants of the laboratory; and without such means of investigation, the subject has not received so much attention as it deserves. The great amount of electricity, of high intensity, that can be thus excited, might probably by some more convenient arrangement be rendered practically useful.

Since the discovery of the evolution of electricity during the emission of high pressure steam, there has been no marked discovery in electric science. During the last ten years, however, there have been numerous ingenious applications of electric force. The power of electricity has been made to subserve almost all kinds of purposes, from the transmission of thought to the performance on musical instruments.

We have endeavoured in the preceding sketch to note and render intelligible those successive stages of discovery and of inductive investigation which have given to electricity, though comparatively a science of recent date, a rank as high, and a character as important and interesting, as that of any other of the physical sciences. Though so much has been done in developing and in practically applying electrical phenomena, much more remains to be accomplished. The field is yet only partially cultivated, a large tract remains unexplored, in which we anticipate succeeding cultivators will bring to li[illegible]onal

facts as extraordinary as any hitherto discovered. Their labours may remove the veil that at present obscures the nature of the connection between frictional electricity, voltaism, heat, and magnetism; they may point out the relations of this agent with other physical forces; and may elucidate the mysterious influence which electricity is known to exercise on the functions of vitality.

PART II.

PHENOMENA OF ELECTRICITY.

THE PHENOMENA OF ELECTRICITY.

CHAPTER I.

GENERAL PROPERTIES.

Static and current Electricity—Electrical excitement by friction—Attraction and repulsion—Illustrative experiments—Electrics and conductors—All substances electrics when insulated—The opposite kinds of Electricity—Negative and positive electrics changeable—Mutual dependence of the two Electricities.

In the foregoing outline of the history of electricity we have traced the progress of the science from the first feeble spark to its identification with the lightning's flash; and thence—pursuing its course into the vast field which the excitement of electric force by chemical action has opened—we have endeavoured to follow its rapid strides since Galvani convulsed the limb of a frog, Volta constructed his wonder-working pile, Davy decomposed the alkalies and earths, and Œrsted detected magnetism in the electric current, till Faraday, reversing the process, has from magnetism eliminated electric fire.

We have now to describe more particularly the great variety of electrical phenomena, and the means by which they are produced in the present advanced state of the science. In doing this we shall proceed nearly in the same order in which the leading facts presented themselves in our historical sketch; commencing, in the first place, with the phenomena of frictional, or as it is more frequently called "static electricity;" the latter term being applied to distinguish the action of the force excited by friction from that excited by chemical action. Frictional electricity exhibits itself in a state of equilibrium, and remains comparatively at rest, excepting during the instant of *discharge*; whilst *voltaic* electricity appears to be constantly in

motion from one pole of the voltaic battery to the other, and has hence been called current electricity.

The friction of a glass rod or stick of sealing wax, used by the early electricians as their only means of exciting electricity, affords the simplest mode of exhibiting the phenomenon of electrical excitement. A glass tube about two inches in diameter and two feet long answers the purpose very well. It should be made perfectly dry, and be then corked at each end; if varnished inside, to prevent the condensation of moisture on the glass, it will be better. Several folds of black silk, on which a metallic amalgam of mercury, zinc, and tin, has been spread, forms the best rubber. On rubbing the tube briskly with the silk, after both have been first warmed, electricity will be excited in almost all states of the atmosphere; and when the weather is fine and frosty, loud cracklings will be heard. In the dark, flashes of light will be observed darting from the tube to the hand that holds it; and on presenting the knuckle within an inch or two of the excited glass, sparks will be emitted, accompanied by a slight tingling sensation.

When a downy feather is held at some distance from the excited tube, the fibres are attracted towards it, and the feather rushes to the glass. In a short time, however, the downy parts will be observed to separate from each other, and the feather, becoming charged with electricity, will fly off nearly as rapidly as it was attracted. The feather when thus repelled from the tube, may be driven about the room by bringing the glass tube near it, by which it will continue to be repelled until it has parted with its charge of electricity.

The feather, when in a charged state, exerts an attractive force on all surrounding bodies equal to that with which it is attracted towards them; and if another feather were suspended near, the two would rush towards each other with equal forces, and with velocities inversely proportioned to their respective weights. The same law also regulates the repelling force; and when two light bodies charged with electricity from the glass tube are suspended near to each other, they are mutually repelled. If two small pieces of cork, for example, or what is still better, two pith balls, are suspended by strings of equal length so as to touch, and they are then charged with electricity from the glass tube, they repel each other and keep apart until they are either touched by a conducting body, or until the electricity is gradually discharged into the air.

The properties of electric attraction and repulsion may be illustrated in a great variety of ways, some of which are extremely amusing. If a number of small figures are cut out in

paper, or carved out of pith, and an excited glass rod be held a few inches above them on the table, the figures will immediately commence dancing up and down, and assume a variety of droll positions. A favourite posture, if we may so express it, of these little figures, is that of standing on the head or on one hand, and presenting a foot towards the glass, their little frames being agitated all the time with a quivering motion. From this position of the figures may be learned the fact that first suggested to Franklin the means of drawing lightning from the clouds. The sharp edges and corners of the paper serve as points to draw off the electricity from the excited glass tube, and each one of the figures in that posture is operating, on a small scale, in the same manner as the lightning-conductor on a church steeple when a thunder-cloud is passing over it. This action of the edges and points in drawing off the electricity at a distance, prevents the figures cut out in paper from dancing so energetically as those made of pith, and pith balls act more briskly than either. The experiment can be shown better by means of an electrical machine than with the excited tube, by suspending horizontally from the prime conductor a metal disc a few inches above a flat metal surface connected with the earth, on which the figures are placed. By this arrangement the dancers have more space for their lateral gyrations, and sometimes waltz together very laughably.

Fig. 1.

Fig. 2.

Experiments illustrative of electric attraction and repulsion may be greatly diversified when an electrical machine is used, so as to increase the quantity of electricity and to conveniently apply it. Among the apparatus commonly employed for exhibiting this property in an amusing manner is a doll's head with long hair.

When attached to the prime conductor of the machin(hairs stand erect, presenting an exaggerated representati fright.

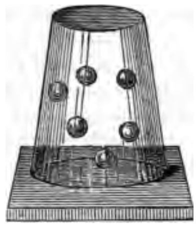


Fig. 3.

A dry glass tumbler be(charged by grasping it with the and presenting the inside to a fixed on the conductor. If it be placed over a number of pith on the table, the balls dance u] down with great rapidity. Eac is first attracted to the top or sides of the glass, and thus bec(charged, it is repelled or falls c table, where it discharges the tricity it has received, and is attracted to the glass. In this ner the tumbler gradually parts the electricity, and the actions balls become more feeble. Th side of the glass is equally ch with the inside, though negat and parts with its electricity t air or surrounding bodies in p tion to the discharge of the in surface; it being a law of st electricity, that one surface of conducting body cannot be ch or discharged without the other. operation of this law will be exp more fully when we come to th sideration of the phenomena o tric induction and the Leyden jar.

Fig. 4.

The bell apparatus for ringing bells affords a good illust of electric attraction and repulsion. A metal rod, fig. 4, horizontally to the prime conductor of the machine, ser suspend three or more small bells. When three bells a ployed, the two end ones are suspended to the rod by wi chains, and the central one is hung by a silk thread to in it from the conductor. Two small metal clappers are als pended by insulating silk threads from the horizonta When the machine is put in action, the bells at each end rod being connected with the conductor by metal conne(become instantly charged with electricity, and attract the cla The latter being thus instantaneously charged are as q *repelled, and* are attracted to the central bell, which is con

with the table by a chain through which the electricity passes to the ground. The clappers are then again attracted and strike against the outermost bells. By these brisk alternate attractions and repulsions they keep ringing as long as the machine is in action. It was by attaching a set of bells of this kind to his lightning-conductor, that Dr. Franklin received notice by their ringing whenever a thunder-cloud was passing over the apparatus.

One of the effects of electrical attraction is exemplified in its action on running fluids, by causing them to flow more quickly. Let a metallic cup, for example, fig. 5, with a small hole at the bottom, be suspended by a chain from the prime conductor of an electrical machine, and pour a little water into it. If the hole be so small as to allow the water to issue only by drops when the machine is not in action, the flow will be increased to a stream as soon as the electricity is excited. The water, in this case, being charged with positive electricity, it is attracted with increased force towards the earth, and that force, added to the attraction of gravitation, produces the more rapid flow.

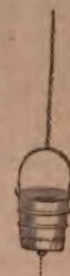


Fig. 5.

The early electricians appear to have had no knowledge of variations in the degree of conducting power, nor of variations of degree in electrical excitement, in different substances. More recent investigations, however, have shown that the different known conductors and electrics are blended together in such inappreciable degrees, that it is impossible to say to which class some of the intermediate bodies belong. For instance, as all substances are more or less capable of electrical excitement, they might consequently be all classed in the list of electrics, gutta percha being at the head, and silver or copper at the bottom of the list. On the other hand, as all substances conduct electricity in various degrees, they might all come within the class of conductors. In the latter case the order of position would be reversed, silver being at the head of the list as the best conductor, and gutta percha at the bottom, as the worst known conductor. So different, indeed, is the conducting power of the bodies usually considered as conductors of electricity, that water, which is classed as a conductor, offers three million times more resistance to the passage of the electric fluid than copper.

It is a remarkable fact in the conduction of electricity, that imperfect conductors can compensate by quantity for their deficiency in quality. Thus, assuming that in equal volumes of copper and water the latter would not conduct more than the three-millionth part of the quantity of electricity in the sa[me] time that would pass by the copper, yet by increasing

quantity of water in a proportionate degree, the resistance in both cases would be equal. We shall have occasion to show, indeed, in speaking of electric telegraphs, that when the conducting power of water is brought to operate on an extensive scale, the resistance it offers to the passage of electricity diminishes to an inappreciable quantity. The difference in the conducting properties of bodies is much more apparent in voltaic electricity than in the more intense state of frictional electricity. The intensity of the latter enables it to force a passage readily through the worst conductors; but the thinnest film of varnish is sufficient to obstruct the voltaic current.

The conductors and non-conductors of electricity are arranged by M. De la Rive in the following order. In the first column are placed those bodies classed as conductors, ranged in the order of their conducting properties, the best conductors being placed at the head of the list. The second and third columns comprise the non-conductors of electricity placed in the reverse order; those at the top being the most imperfect insulators. Thus if they were placed in one column they would form a continuous range, from the top downwards, of conducting bodies, the metals being the best conductors, and shellac and gutta percha the worst. It is impossible in fact to draw a distinctive line where conduction ends and insulation commences:—

CONDUCTORS.	ELECTRICS.	
All the metals.	Dry metallic oxides.	Dry gases and air.
Well burned charcoal.	Oils; the heaviest are best.	Leather.
Plumbago.	Ashes of vegetable bodies.	Parchment.
Concentrated acids.	Ashes of animal bodies.	Dry paper.
Diluted acids.	Strong dry transparent crystals.	Feathers.
Saline solutions.	Ice below 13° Fahr.	Hair, wool.
Metallic ores.	Phosphorus.	Dyed silk.
Animal fluids.	Lime.	White silk.
Sea water.	Dry chalk.	Raw silk.
Spring water.	Native carbonate of barytes.	Transparent precious stones.
Rain water.	Lycopodium.	Diamond.
Ice above 13° Fahr.	Caoutchouc.	Mica.
Snow.	Camphor.	All vitrifactions.
Living vegetables.	Some siliceous, and argillaceous stones.	Glass.
Living animals.	Dry marble.	Jet.
Flame.	Porcelain.	Wax.
Smoke.	Dry vegetable bodies.	Sulphur.
Vapour.	Wood that has been strongly heated.	The resins.
Salts soluble in water.		Amber.
Rarefied air.		Gum lac.*
Vapour of alcohol.		
Vapour of ether.		
Earths and moist rocks.		
Powdered glass.		
Flowers of sulphur.		

* Gutta percha is one of the best non-conductors, though no place is assigned to it *in this table.*

We have previously noticed that the best electrics are the worst conductors of electricity, and that all substances may be considered to be electrics or non-electrics in proportion to the resistance they offer to the conduction of electricity. As gutta percha offers more resistance to the passage of electricity than any other body, it may consequently be considered the best electric; and metals, being the best conductors, should be the farthest removed from the condition of electrical excitement. But the conditions of the two bodies may be reversed by insulating the one and by covering the other with a conductor. A rod of gutta percha when moistened with water gives no indication of electricity, because the water conducts it away the instant that it is excited, and copper might be made to yield electricity if properly insulated. If a rod of copper be fixed to a gutta percha handle, and the copper be warmed and then rubbed with a very thick rubber of wadded silk, or hare skin, it will emit a bright spark. The electricity exhibits itself differently, however, from that of an excited glass rod, for on account of the good conducting powers of the metal it parts with the charge at once, by a single spark, instead of giving a succession of small sparks from different parts of the surface.

It seems probable that electricity is always excited by friction under every circumstance, though it is only observable in those substances that have the power of retaining it on their surfaces after being excited. The mere movement of the feet along the carpet is sufficient to excite electricity; as may be shown by placing the hand on a delicate electroscope whilst the feet are in motion.

The experiment which led Du Fay to the discovery that there are two kinds or states of electricity may be easily repeated. Having caused a feather to be repelled from an excited glass tube, excite a stick of sealing wax, and the feather which has been repelled by the glass will be attracted by the wax. Then holding the glass tube in one hand and the gutta percha in the other, the feather will be alternately attracted and repelled, and with greater force than when a conducting body connected with the earth is brought near to either of the excited electrics and the feather. After a succession of attractions and repulsions, the electricity of the excited glass and of the wax is discharged, the feather having acted as a discharger from one to the other. This experiment clearly shows that the electricity excited in glass, whilst it apparently repels bodies similarly electrified, attracts those that are electrified by wax. The phenomenon of mutual attraction is shown more briskly [illegible] piece of gold leaf or suspended pith ball be substituted for

feather; for the downy fibres of the latter tend to diss the electricity quietly from their distended points, and prevent the feather from becoming fully charged.

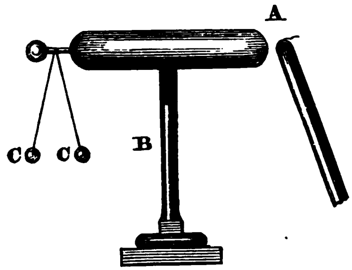


Fig. 6.

A still more satisfa way of exhibiting the diff actions of the two kin electricity is to suspend pith balls by threads of lengths from an insu metal conductor, as repre ed in fig. 6. The pith bal are suspended from one e the horizontal metal cyl A, and insulated from the by the glass leg B, fixed i wooden base.* Touch th A with an excited glass tube, and the pith balls will separat will continue apart when the tube is removed, each one l electrified with the electricity of the glass. If an excited of sealing wax be then brought near, the expanded balls collapse, even before the wax touches A. On removing th cited wax without touching the horizontal rod, the pith will again separate, and will be in the same electrical cond as before. But if the excited stick of wax come in contact the rod, or approach it so closely as to transmit a spark state of electricity becomes changed, and the balls will the pand with the opposite kind of electricity. When the ex wax is afterwards brought near, the pith balls will expand widely instead of collapsing as they did before, and the ex glass tube, which previously made the balls expand, will cause them to collapse.

This experiment clearly shows that the electricity comn cated to the balls by the excited glass, differs materially i attractive conditions from that communicated by the ex wax, and as the one kind of property is conferred by the and the other by the wax or rosin, the terms *vitreous* and *resi* applied to the two kinds of electricity by Du Fay, are appar very appropriate. We shall, however, in the next chapter, e vour to show that the different phenomena may be equally and more simply ascribed to different states of the same of electricity.

Shortly after the discovery of the two electrical condition

* Very convenient and much more economical small insulating stands ar made altogether of gutta percha, and may be procured from Mr. Griffin of I *Row, London.*

the known electrics were classed according to the kind of electricity each one excited. Such classification, however, was afterwards found to be very fallacious, for the kind of electricity excited depends, with few exceptions, on the nature of the rubber employed. Even glass and rosin, which are considered the types of the two distinct classes of electrics, may be made to interchange their states of electrical excitement. Glass, for example, when rubbed with the fur of a cat yields resinous electricity, and rosin becomes vitreously electrified when rubbed with metals. The fur of a cat is the only known substance that does not alter its electrical state with whatever it is excited.

In the following list of electrics, those which come first excite vitreous or positive electricity when rubbed with any of those that follow, and resinous or negative electricity when rubbed with those that precede them :—

Fur of a cat.	Feathers.	Silk.
Polished glass.	Wood.	Gum lac.
Woollen cloth.	Paper.	Rough glass.

The change of electrical excitement seems to depend more on the nature of the surface than on the inherent quality of the electric; for in the preceding list it will be observed that glass is positive when polished, and is strongly negative when roughened. The following table, given by Cavallo as the results of experiments, shows more fully the changes effected by different rubbers. It will be observed, however, that the relative electrical conditions do not exactly agree with those mentioned in the foregoing list :—

Substances excited.	Kind of electricity.	The rubbers.
Back of a cat,	Positive,	Every substance tried.
Polished glass,	Positive,	Every substance but the back of a cat.
Rough glass,	Positive,	Dry oiled silk, sulphur, metals.
	Negative,	Woollen cloth, paper, wax, the human hand.
Tourmalin,	Positive,	Amber, a current of air.
	Negative,	Diamond, the human hand.
Hare skin	Positive,	Metals, silk, leather, hand.
	Negative,	Finer furs than hare skin.
White silk,	Positive,	Black silk, metals.
	Negative,	Paper, hand, hair.
Black silk,	Positive,	Sealing wax.
	Negative,	Furs, metals, hand.
Sealing wax,	Positive,	Metals.
	Negative,	Furs, hand, leather, cloth.
Baked wood,	Positive,	Silk.
	Negative,	Flannel.

These facts respecting the change of electrical state from positive to negative are difficult to explain on any present hypothesis. *The frequent changes* of state which we shall

further occasion to notice, presents, indeed, one of those mysteries of electric science of which no satisfactory explanation has hitherto been afforded.

One of the remarkable features of the two electricities is their intimate connection with, if not their dependence on, each other. Positive electricity cannot be excited without the excitement at the same time of an equal amount of negative; nor can the latter be excited without the evolution of positive electricity. Thus, when a tube of glass held in the hand is rubbed with silk, the hand holding the silk has a quantity of negative electricity communicated to it equal to the positive electricity excited in the glass. In ordinary circumstances the negative electricity is not apparent, because it is conducted to the earth as quickly as it is evolved; but when the person who is exciting the glass tube is insulated from the ground, sparks of negative electricity may be taken from any part of his body.

CHAPTER II.

INDUCTION AND THEORY OF ELECTRICITY.

Induction of electricity at a distance — Assumed continuous chain of polarized particles — The electrophorus — Influence of induction in thunder-storms — The electrometer — The condenser — Coulomb's torsion balance — Various inductive powers of electrics — The two theories of electricity.

It was stated in the preceding chapter that one kind of electricity cannot be excited without exciting at the same time an equal amount of electricity of the opposite kind. This close association of positive and negative electricity is not confined to the moment, nor to the place of their development, but it may be said to extend throughout all space. When an electrified body is removed altogether from the source of excitement, its presence induces in all bodies at a distance the opposite electrical state. When, for example, an excited glass tube is placed at the distance of a foot from the end P of the horizontal insulated metal cylinder N P, furnished with pith balls at each end, the balls will be immediately distended by the influence of the excited tube, though no electricity is communicated to them directly from the glass. On the removal of the tube the balls collapse, and no trace of electricity can be detected in the rod. But if the finger or any other conducting body touch the end N whilst the balls are distended under the influence of the glass tube near P, and the finger is withdrawn whilst the influence is exerted, *then* on removing the tube the balls will remain distended, the rod having received a charge of negative electricity. The electrical state of the balls may be easily tested by bringing the glass tube near them again, when they will be seen to collapse on its approach, instead of expanding as at first.

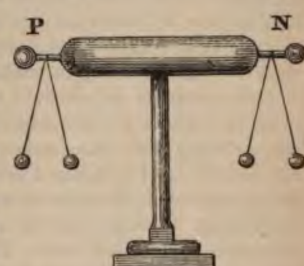


Fig. 7.

Discharge the electricity from the rod and again bring the excited glass tube near the end P. Whilst the balls are distended, let an excited stick of sealing wax be brought near the same end, and they will partially collapse; but if the excited wax approach towards the other end, they will be separated still farther apart.

In these experiments it will be observed that the approach of a positively excited electric towards one end of the insulated rod, imparts electrical properties of opposite kinds to the two ends of it. The end nearest the positive electric exhibits signs of negative electricity, and the farther end becomes positively electrified. The rod has not, however, received any charge of electricity, for the instant that the electric is removed it returns to its natural state. The mere presence, therefore, of the excited electric induces a change in the electrical state of the rod, and coerces the positive electricity to one end, and attracts the negative electricity to the other.

These simple experiments afford excellent illustrations of the important property of *induction;* and they should be, therefore, carefully studied in all their bearings. The fact has been satisfactorily established that every excited electric induces electricity of an opposite kind in all surrounding bodies; and that this influence is exerted through the air or any other non-conducting substance with instantaneous rapidity. There is no actual communication of electricity in these cases, for the bodies in which electricity is induced lose their electrical condition the instant that the excited body is withdrawn.

This exertion of electric force on bodies at a distance, bears some analogy to the transmission of light through the air without illuminating the transparent medium through which it passes. According to Professor Faraday's view of inductive electrical action, however, there is a connecting chain of polarized particles extending through the non-conducting bodies by which the influence is transmitted. The inducing force is considered by him as being transmitted to a distance through the intervention of the contiguous particles of the air, each of which becomes polarized with negative and positive electricity, in the same manner as a number of insulated conducting bodies when placed in continuous connection. The following experiment is adduced as illustrating this polarizing action of electricity on the air:— Let two brass balls be introduced into a glass vessel containing oil of turpentine, with which there has been mingled a number of fine shreds of silk. When one of the balls is connected with an electrical machine in action, and the other ball is connected *with the earth*, the shreds of silk arrange themselves in con-

tinuous lines between the two balls; for though the electricity cannot pass directly through the non-conducting turpentine, electricity is induced in the second ball, and the disposition of the particles of silk shows the assumed condition of the molecules of air which form connection between an excited electric and a distant conductor. How far the influence extends has not been ascertained, but it most probably obeys the same laws as heat and all other radiant forces; extending indefinitely into space, but diminishing in intensity inversely as the squares of the distance.

The property of induction is admirably illustrated by a very ingenious and useful apparatus invented by Volta, called the electrophorus. It consists of a thick flat cake of resinous substance laid upon a sheet of metal. The resinous cake being rubbed with hot flannel, the upper surface becomes charged with negative electricity, which induces an equal positive charge on the under surface in contact with the metal plate. A metal disc insulated by a glass handle is then pressed upon the excited rosin. The effect of this application is to induce electricity of opposite kinds on both surfaces of the disc. The surface nearest the rosin is charged positively, and the upper surface is charged negatively so long as they remain under the influence of the excited electric. There is, however, no communication of electricity to the metal disc, and if it be lifted up it will be found not to retain any portion of the electricity though pressed into contact with the rosin. The natural electricity of the metal is disturbed from its normal condition by the influence of the excited electric, but when removed from the sphere of that influence it returns to its original state of neutrality. But if, whilst the disc remains on the rosin, and the upper part is negatively electrified, the surface be touched with a conductor, a spark passes, and when the disc is again lifted up it will be found to be charged positively. This operation may be repeated any number of times, for none of the electricity of the excited rosin is communicated directly to the disc, which becomes electrical merely by the induction of opposite kinds of electricity on its two surfaces; the equilibrium of its natural state being disturbed by the attractive force of the excited electricity.

When a plate of glass is substituted for one of rosin, the electricity with which the disc is charged of course becomes reversed. The upper surface is then positive whilst under the influence of induction, and on allowing that positive electricity to escape by communication with the earth, the metal when removed from contact is in the negative state.

The continued supply of electricity from an electrophorus by a single excitement of the resinous plate renders this instrument occasionally very useful in electrical experiments, where a small quantity of electricity only is required. Fig. 8 represents the apparatus as generally constructed. The cake of resinous matter, A A, is poured into a circular metallic tray; C is the metal disc, usually made of brass, rounded at the edges; and B is the glass handle for the purpose of insulation. A sheet of gutta percha is sometimes advantageously substituted for the rosin, and a gutta percha handle fixed to a tin disc, serves for the electrophorus plate. This arrangement is in several respects more convenient, and it possesses the advantage of being much cheaper.

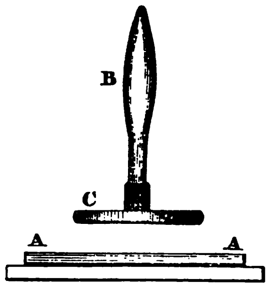


Fig. 8.

The induction of electricity through glass may be shown by exciting one side of a thin plate when laid flat on the table. The glass when rubbed with silk becomes positively electrified on its upper surface, and the under surface is at the same time charged with negative electricity. This may be shown by lifting the glass by the corners and bringing it near the pith balls (fig. 7), after they have been distended by contact with an excited glass tube. The balls will be distended farther when the upper surface of the pane of glass is presented to them, and they will collapse on the presentation of the under surface.

When an excited glass rod is held in the middle of the room, the walls and everything they enclose are under its inductive influence, though it may be too feeble to be appreciated. The effect of the excited glass is to attract a certain portion of negative electricity towards it, and a mutual attractive force is exerted between the excited glass and every object thus influenced. Many persons are painfully sensitive of the approach of a thunder-storm, and often complain that there is "thunder in the air," even when no storm succeeds. There can be no doubt that during the passing of a thunder-cloud electricity is induced in all bodies beneath; and Faraday on this account considers it dangerous to have iron roofs to powder magazines. Such a roof might have electricity induced in it by the action of the electricity in the cloud, and a spark might pass from the under surface of the roof to the ground.

The following experiment has been adduced as an illustration *of this danger.* One end of a horizontal cylinder, in[...]d on a

glass stand, is adjusted close to a jet of gas issuing from a gas burner. If an excited glass rod be brought suddenly near the other end of the cylinder, a spark will pass between the brass burner and the cylinder, and the jet of gas will be inflamed. Having extinguished the flame, quickly withdraw the excited tube, and the gas will be again ignited by the return of the positive electricity expelled from the cylinder when under the influence of the excited electric, from which, however, no charge has been directly received.

The action of that useful instrument, the electrometer, depends for the most part on the induction of electricity. The simplest indicator of electrical excitement is the arrangement of two pith balls, already shown in fig. 6. The weight of the balls, however, and the imperfect conducting character of the suspending string, prevent it from being very sensitive. Bennet's gold leaf electrometer is a much more delicate instrument. It consists of a wide glass tube, about four inches long, mounted on a metal stand, and covered with a metallic cap. From the inside of the cap there is a small projection, to which two thin strips of gold leaf are attached. The extreme lightness of the gold leaf and its great conducting power render this instrument extremely sensitive to the action of small quantities of electricity.

Its sensitiveness is increased by fixing strips of tin foil connected with the brass stand of the instrument opposite to the gold leaves, by which means the induced electricity is brought into closer action, and the leaves diverge with a very slight degree of electrical excitement.

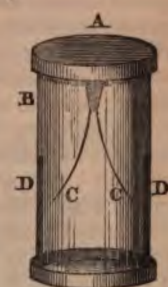


Fig. 9.

Fig. 9 represents the simplest form of this useful indicator of the presence of electricity. The brass cap A fits closely on to the tube B, and from the cap the gold leaves C C are suspended. Two strips of tin foil, D D, are connected with the metallic base, and through it with the earth.

This instrument, and others of a similar construction, though called *electrometers* do not indicate the quantity of electricity; and the name *electroscope*, which has been recently applied to them, is more appropriate to their character.

To increase the sensibility of this electrometer, metal discs, called condensers, are added; one of which is attached to the brass cap, and the other is mounted on a support that is moveable by a joint at the bottom, so that it may be removed to the position indicated by the dotted lines in the figure. By the in-

duction of electricity on the surface of the moveable disc, and by its reaction on the electrometer, an accumulation of the electric force is effected; by which means the presence of otherwise inappreciably small quantities of electricity is detected.

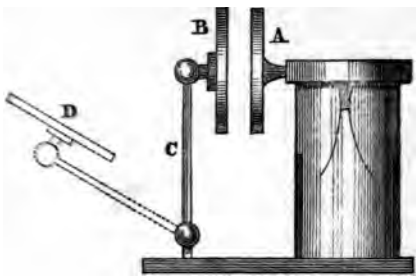


Fig. 10.

The effects of condensers depend entirely on the peculiar action of induced electricity. As the inductive influence radiates in all directions from the surface of the excited electric, its force diminishes in proportion to the distance at which it operates. It has been ascertained that in this respect induction obeys the law that regulates the diffusion of all other radiant emanations, and that its intensity diminishes according to the square of the distance. Thus, at a distance of two feet the intensity is only one fourth of its force at a distance of one foot, but its influence is spread over a surface of four square feet instead of one. The nearer, therefore, any body is brought to an excited electric—provided it be not so close as to communicate the electricity directly—the more powerful is the electrical induction. When, for instance, the disc A of the condenser has no opposing surface near it, the inducing influence is diffused over a large expanse and becomes so feeble that the reaction on the electroscope is imperceptible. But when the disc B is placed very near to A the electricity with which the latter is charged induces an amount of electricity in that disc nearly equal to its own, but of the opposite kind; for if A is positive B will be negative. If the second disc is insulated and is touched with a conductor when under the influence of A it will be charged negatively, and in that condition it reacts on the positive electricity in A and the gold leaves will collapse. In this condition a further charge from the original source of electricity may be communicated to the electroscope, and a further quantity of electricity will be induced in B. By again touching that disc it becomes charged with the additional quantity of electricity induced, and if removed will continue negatively electrified. Immediately that its reaction on A ceases the electricity which was disguised by the counteracting presence of the negative disc becomes free, and the gold leaves diverge more than at first, for a double charge has been given to the

electroscope. By repeating this operation several times a very feeble manifestation of electricity may be increased in intensity so as to strongly affect the electroscope, for each increasing charge by induction given to the disc B tends more powerfully to neutralize for the time the charges communicated to A, and enables it to absorb fresh supplies from the original source.

The torsion balance of Coulomb, which has been previously noticed, measures the electric force exerted, and may therefore with strict propriety be called an electrometer. It consists of a fine rod of shellac, c, at each end of which there is a gilded pith ball, the rod and balls being suspended from the centre by a filament of spun glass *a*. The ball *d* is similar to the others, and is also fixed to a rod of shellac, with a corresponding ball at the other end. The latter is called the carrier ball, as it conveys electricity from the body to be tested to the electrometer. When applied to the excited body under examination, it receives a portion of the electricity, and on being then placed in its position in the instrument, the suspended ball that rests against it is repelled. By turning the screw *b* the two balls may be brought together; and the amount of torsion or twist given to the filament of glass, so as to overcome the electrical repulsion, is measured by a graduated scale.

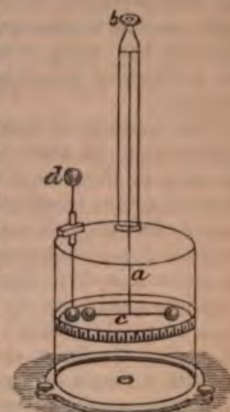


Fig. 11.

The action of electrical induction takes place through all non-conducting bodies, though not with equal facility; the transmission of the influence being most apparent through those substances which are the worst conductors of electricity. The term *dielectrics* has been given to those bodies that permit induction to take place through them; but it seems to be a useless multiplication of names, since all electrics are also dielectrics. The following has been ascertained experimentally to be the comparative order of the inductive power of the principal electrics:—

Specific Inductive Capacity.

Air,	1·00	Glass,	1·90
Rosin,	1·77	Sulphur,	1·93
Pitch,	1·80	Shellac,	1·95
Wax,	1·86		

An important portion of Faraday's *Experimental Researches in Electricity* is occupied with investigations respecting the nature of inductive action. He has arrived at the conclusion that induction "is a physical action occurring between contiguous particles, never taking place at a distance without polarizing the molecules of the intervening dielectric, causing them to assume a peculiar constrained position, which they retain so long as they are under the coercing influence of the inductive body." According to this view of the question, therefore, all the particles of air, and of every solid non-conductor, must assume a polar arrangement under the influence of induction in the same manner as particles of iron filings spread on a sheet of paper become polar under the influence of a magnet.

The property of induction is now adduced to explain every phenomenon of static electricity; irrespective of the opposing theories of the two electricities, or of the mode by which inductive action is effected. According to this view of electrical action, the phenomena of attraction and repulsion are thus explained:—The two opposite states of electricity being admitted to exert a mutual attraction on each other, the induction of negative electricity by positive, and the reverse, is attributed to a mutually exerted attractive force. Again, the repulsion of bodies similarly electrified is considered to be caused by attractive forces exerted in opposite directions, and not by any operating repulsive power exerted among the particles of such bodies. Two similarly electrified pith balls, for example, are supposed to diverge in consequence of each one inducing an opposite state of electricity in surrounding bodies. As each ball has received a charge of the same kind of electricity, neither of them possesses the power to induce an opposite electrical state in the other, consequently there is no attraction between them, and they are free to be acted on by surrounding bodies; the divergence and apparent repulsion from each other being occasioned altogether by attractive forces acting at a distance. The existence of a negative force, as repulsion may be regarded, is indeed opposed to the principles which have been established by investigation in other departments of physical science; and by the hypothesis of inductive action the student of electricity is called upon to dismiss the action of repulsion from operating forces, as the student of chemistry is compelled to deny the existence of cold as a positive property. It seems questionable, however, whether the term "induction" has not been introduced unnecessarily, since all the phenomena may be regarded as the results of electrical attraction.

e question whether there are two distinct kinds of elec-
y, or only one kind which is exhibited in different states of
sity, though highly interesting in a theoretical point of
, is not essential to the explanation of electrical phenomena,
h may be almost as readily explained by one hypothesis as
he other. We shall throughout this work adhere to the
simple theory, which regards all electrical phenomena as
eding from the disturbance of electricity of the same kind,
h is inherent in all bodies; in the same manner as the sen-
ns of heat and cold are produced by different degrees of the
acting power. The more simple character of the *plus* and
s theory, as well as the analogy it bears to the known
ns of the other powers of Nature, incline us strongly in its
r.

e foundation on which the Franklinian theory rests is thus
l by Dr. Priestley: "According to this theory, all the
tions of electricity depend upon one fluid *sui generis*,
mely subtle and elastic, dispersed through the pores of all
s; by which the particles of it are strongly attracted, as
are repelled by one another. When the equilibrium of
fluid in any body is not disturbed, that is, when there is
y body neither more nor less of it than its natural share,
an that quantity which it is capable of retaining by its own
ction,—it does not discover itself to our senses by any effect.
action of the rubber upon an electric disturbs this equi-
m, occasioning a deficiency of the fluid in one place and
undancy of it in another. This equilibrium being forcibly
rbed, the mutual repulsion of the particles of the fluid is
sarily exerted to restore it. If two bodies be both of them
harged, the electric atmospheres repel each other, and both
odies recede from one another to places where the fluid is
lense. If both bodies be exhausted of their natural share
is fluid, they are both attracted by the denser fluid existing
r in the atmosphere contiguous to them, or in other neigh-
ing bodies; which occasions them still to recede from one
her as much as when they were overcharged."*

e statement of the theory of vitreous and resinous electricity
hall also take from Dr. Priestley, who, though an advocate
he single fluid hypothesis, has stated the arguments for and
st both with great impartiality:—

Let us suppose, then, that there are two electric fluids
h have a strong chemical affinity with each other, at the
time that the particles of each are as strongly repulsive of

* *Priestley's History of Electricity.*

one another. Let us suppose these two fluids in some measure equally attracted by all bodies, and existing in intimate union in their pores; and while they continue in this union, to exhibit no mark of their existence. Let us suppose that the friction of any electric produces a separation of these two fluids, causing the vitreous electricity of the rubber to be conveyed to the conductor, and the resinous electricity of the conductor to be conveyed to the rubber. The rubber will then have a double share of the resinous electricity, and the conductor a double share of the vitreous; so that upon this hypothesis no substance whatever can have a greater or less quantity of electric fluid at different times. The quality of it only can be changed. The two electric fluids being thus separated will begin to show their respective powers, and their eagerness to rush into reunion with one another. With whichsoever of these fluids a number of bodies are charged, they will repel one another, and they will be attracted by all bodies which have a less share of that particular fluid with which they are loaded; but will be much more strongly attracted by bodies which are wholly destitute of it, and loaded with the other. In this case they will rush together with great violence.

"Upon this theory every electric spark consists of both fluids rushing contrary ways and making a double current. When, for instance, I present my finger to a conductor loaded with vitreous electricity, I discharge a part of the vitreous and return as much of the resinous, which is supplied to my body from the earth. Thus both the bodies are unelectrified, the balance of the two powers being perfectly restored."

Dr. Priestley proceeds to state, with great fairness, the analogies and the facts which may be adduced in support of the two distinct electric fluids. The combination of two caustic and powerfully active substances, as an alkali and an acid, in the form of a neutral salt, in which the properties of neither of the constituent parts is perceptible, is one of the analogies advanced in favour of the vitreous and resinous fluids being combined, and rendered perceptible only when their combination is disturbed.

It appears from the preceding consideration of the properties of the two conditions of electricity, that the cause of electrical attraction is the endeavour made to combine and return to a neutral state. This attractive power, which is extended in the phenomena of induction to all distances, seems to afford sufficient explanation of the cause of those phenomena, without supposing the exertion of any separate action of inductive force. And if we concur in the explanation assigned for the mutual

sion of similarly electrified bodies, and attribute their ap-
t repulsion to attractions in opposite directions, then the
tions of the two electricities will supply adequate cause
l the phenomena of repulsion without the necessity of sup-
g that there exists any positively active repulsive power in
icities of the same kind.

CHAPTER III.

DIRECT DEVELOPMENT OF ELECTRICITY.

Electrical machines; Cylinder, Plate, and Gutta Percha—Influence of points—Explanation of the cause—Frictional electricity confined to surfaces—Intensity of machine-excited electricity—Inflammation of combustibles by the spark—Resistance of the air—Nature of Electric discharge—Disruptive, brush, and glow discharge—Colour of the electric spark.

THE excitement of electricity by friction with the hand is sufficient to illustrate the primary phenomena and elementary properties of the electric fluid; but for the exhibition of its powerful effects and more complicated actions, it is requisite to employ other apparatus. The quantity excited must be greater in a given time, and means must be provided for collecting and accumulating the electricity when excited.

The electrical machines that were used by Du Fay and Priestley consisted of a sulphur globe whirled round on an axis,

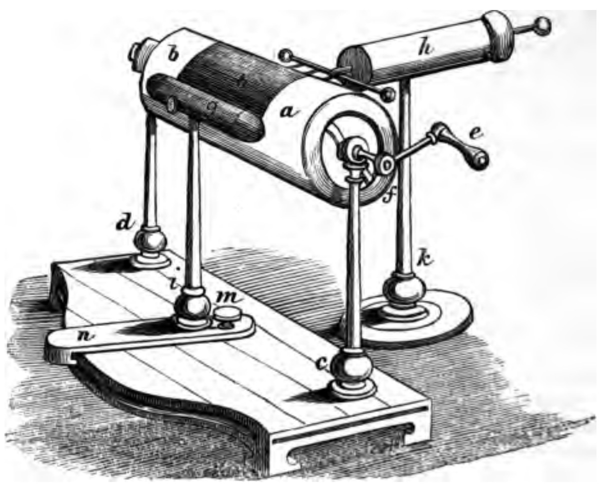


Fig. 12.

with the hand applied for a rubber. The globes of sulphur were supplanted by cylinders of glass; and though that form

has in a great measure given place to the more powerful plate-machine, the cylinder is so well suited for purposes of general experiment, that it continues to be preferred in cases where no extraordinary power is required.

Figure 12 represents this kind of electrical machine. The cylinder, *a*, is mounted horizontally upon supports of varnished glass, to insulate it from the ground. The rubber, *g*, consists of a hair cushion covered with leather, over which is placed a flap of black silk. The cushion is mounted on a glass support, for the purpose of insulation when the exhibition of negative electricity is required; and it is adjusted by a screw, *m*, to regulate the pressure on the cylinder. In the ordinary working of the machine the cushion is connected by a chain with the ground, whence the supply of electricity is derived. A hollow brass or tin cylinder, *h*, rounded at the ends, and placed at a short distance from the glass cylinder, serves to collect the electricity as it is excited. On the side facing the glass there is a row of metal points which facilitate the collection of electricity, and to prevent it from passing off to the earth the metal cylinder, called the prime conductor, is mounted on a varnished glass support, *k*. For the convenience of attaching apparatus to the prime conductor, holes are made on the top and at one end. In some electrical machines a metal cylinder similar to that of the prime conductor is attached to the rubber, as represented in the woodcut, for the purpose of making experiments with negative electricity. In large cylinder machines the prime conductor is usually mounted on a separate stand, detached from other parts of the apparatus, as shown in the figure; but moderately sized instruments are generally constructed with the conductor attached to the same base as the cylinder, an arrangement being contrived to allow of its adjustment at different distances.

A cylinder electrical machine of about nine inches diameter is sufficiently large for ordinary purposes of experiment. An apparatus of that size will, under favourable circumstances, fully charge a quart Leyden jar with twelve turns of the handle.

Little need be said in explanation of the action of this machine, since it is only a modification of the means of electrical excitement by the friction of a glass tube with the hand. On turning the handle, *e*, friction is produced between the surface of the cylinder and the rubber; the electrical equilibrium is thereby disturbed, and electricity is excited, which, when the prime conductor is removed, exhibits itself in bright flashes of light round the cylinder. When the points of the prime conductor are presented to the revolving cylinder, the electricity is *immediately transferred* to it, and it emits sparks to any con-

ducting substance brought near. The electricity thus abundantly excited is supplied from the earth to the rubber, which is continually having its supply drawn from it by the coercive force called into action by friction with the glass. That the electricity is derived from that source is evident from the great diminution of quantity when the metallic connection between the rubber and the ground is removed. In that insulated state the rubber becomes strongly charged with negative electricity, and sparks pass between it and any conducting body brought near almost as abundantly as from the prime conductor when in full action.

The *rationale* of the excitement of electricity by the machine is, according to the Franklinian theory, very simple. The friction of the glass and silk, by disturbing the electrical equilibrium, deprives the rubber of its natural quantity of electricity, and it is therefore left in a negative state, unless a fresh quantity be continually drawn from the earth to supply its place. The surplus quantity is collected on the prime conductor, which thereby becomes charged with positive electricity. On the hypothesis of two distinct electric fluids, the same frictional action causes the separation of the vitreous from the resinous electricity in the rubber, which therefore remains resinously charged. The object of making a connection with the ground, according to this hypothesis, is to restore the proportion of vitreous electricity of which the rubber has been deprived.

The electrical excitement of the machine is greatly increased by applying to the rubber a metallic coating, consisting of an amalgam of zinc, tin, and mercury. It is prepared by melting together two parts by weight of zinc, and one of tin, with which, whilst in a melted state, six parts by weight of mercury are mixed. The mass is shaken well together till it cools, and it is then pounded finely in a mortar and mixed with lard to the consistence of a paste. The amalgam is spread on the cushion only, care being taken to prevent it from being spread on the silk flap.

The effect of an amalgam of this kind in increasing the electrical excitement is very decided, though some difference of opinion exists as to the principle on which the action depends. It has been imagined that the amalgamated metals are oxydized during the friction with the rubber, and that the electricity is due to chemical action. The more simple explanation appears to be, that the coating of metal on the rubber assists in conducting the electricity from it. The use of the silk flap is merely to prevent the electricity from discharging itself into *the air before it* reaches the conductor, and it would be unneces-

sary if the collecting points were brought near the rubber. The adhesion of particles of amalgam to the silk flap which frequently occurs, is prejudicial to the action of the machine by forming conducting points for the dispersion of the excited electricity into the air.

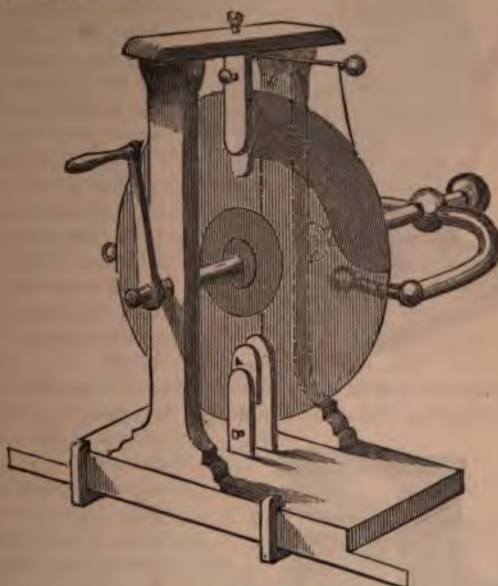


Fig. 13.

Plate machines are now much used on account of the greater quantity of electricity that can be excited by that arrangement of the instrument. A disc of glass about a quarter of an inch thick has an axis fixed in its centre, firmly supported by two cheeks of baked wood. On the upper and lower parts of these cheeks, four cushions are fixed to press against both sides of the glass plate at the top and at the bottom. Small flaps of silk are attached to the cushions to prevent the electricity excited from being dissipated before it arrives at the collecting points of the prime conductor. The conductor itself is also fixed to the upright cheeks, but is insulated from them by a horizontal glass support. Rows of points serve to collect the electricity from both sides of the glass plate. By this arrangement a much larger surface of glass is exposed to friction, and two or more rubbers can be employed on each side of the plate. The sur-

exposed to friction in a plate machine with a glass disc of only one foot in diameter, is more than double that of a nine-inch cylinder machine. A very compact arrangement of the plate machine, which is at the same time very powerful, has been contrived by Mr. John J. Griffin, as represented in the accompanying woodcut.


Fig. 14.

The inconvenience of a plate machine, as usually constructed, arises from the imperfect insulation of the rubbers, in consequence of which the negative electricity excited cannot be exhibited.

An electrical machine in which the excited surface consisted of gutta percha, was shown amongst the philosophical instruments at the Great Exhibition. An endless band of gutta percha, A, (fig. 15) was stretched over rollers, B B, placed above each other about two feet apart. The rotation of the upper roller communicated a rapid vertical motion to the band of gutta percha, which was pressed against at the top and bottom by hard hair brushes, C C, that served as rubbers. The electricity was collected on each side by a branching conductor, D, armed with points, and concentrated in a similar manner to the arrangement of the plate machine.

Fig. 15.

Though we have not had an opportunity of trying the effect of this machine, we have heard it very favourably spoken of.

It presents some practical advantages that would make it preferable to a glass machine.* Sheets of gutta percha may also be attached to discs of wood to serve instead of glass in plate electrical machines. It may be observed, however, that the gutta percha has a tendency to condense and absorb moisture from the atmosphere; therefore it requires greater care in drying than glass to make it efficient as an electric and non-conductor.

With an electrical machine of any of the kinds mentioned, most of the phenomena of electricity can be exhibited in a much more convenient manner than by an excited glass tube, and some of them could scarcely be manifested without the aid of such an apparatus. It is requisite, however, for its due action, that the machine should be placed before the fire for a short time before it is used, to expel the moisture that adheres to the glass and the cushion, and that the insulating glass supports should be rubbed with a warm silk handkerchief. These conditions being attended to, and the rubber being covered with amalgam, the prime conductor will emit dense sparks two or three inches in length when the handle is turned rapidly. The action of the apparatus will, however, be considerably influenced by the state of the weather, whatever precautions be taken to keep it dry. On a fine frosty day the sparks emitted will be longer and more abundant than can be obtained when the atmosphere is charged with moisture, because the damp air acts as a conductor in restoring the electrical equilibrium.

The peculiar influence of points in withdrawing the charge from an electrified body may be readily shown by fixing a pointed wire to the prime conductor of an electrical machine. When the point is attached, the apparatus appears to be deprived of its power of exciting electricity, and but few and very feeble sparks can be obtained. If the room be darkened, rays of light will be seen issuing from the point into the air in the form of a cone, of which the point is the apex, the light being brighter there, and diminishing as the rays expand. When the point is fixed to the insulated rubber, charged negatively, the effect is the same in the dispersion of the charge, but the appearance is that of a star instead of a luminous cone. These different appearances of the electric light at the rubber and at the prime conductor, induced Franklin to infer that the latter emitted electricity, and was consequently in a positive state, and that the rubber was negatively electrified—the *plus* and *minus* hypothesis being assumed.

* The Jurors' Reports of the Great Exhibition made very favourable menti[on of] this *machine*.

On presenting the back of the hand to a metal point fixed on the prime conductor, a sensation similar to that produced by a small blast of air will be perceived. Several kinds of apparatus have been contrived to exhibit the action of the force, whatever it may be, that issues from or is induced towards electrified points. The most simple of these contrivances is the electrical jack, which consists of four light pieces of wire placed crosswise, and balanced horizontally on a pivot in the centre. The ends of these wires are pointed, and are bent in the direction of a tangent to the circle described by the apparatus during its rotation on its axis.

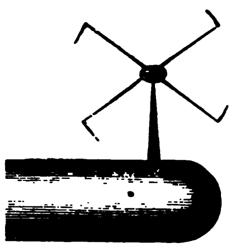


Fig. 16.

When attached to the prime conductor, as represented in fig. 16, and the machine is put in action, the blasts from the bent points cause the air against which they strike to react on the apparatus, and to turn it rapidly round; in the same manner that water or steam issuing from jets similarly directed turn water-mills and model steam engines, by the reaction of the water and of the air.

Another and very curious experiment, which is adduced as proving the emission of some active force from an electrified point, is the following:—Put a little sealing wax at the end of the pointed wire A, fig. 17, and whilst the electrical machine is in action, melt the wax. A thread of sealing wax finer than a spider's web will then be propelled from the point; and, if a piece of white paper be held near, the convolutions of the web-like films, as they overlap each other, produce a remarkable and sometimes a beautiful effect.

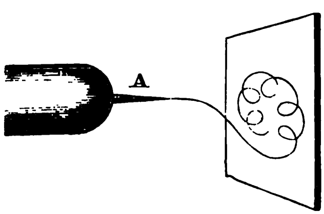


Fig. 17.

It might be supposed, if electricity be emitted only from the positive prime conductor, and the insulated rubber be electrified negatively, that by having its natural share of electricity abstracted from it, there would be no emission from the point fixed to the rubber, but rather an influx towards it. This, however, is not the case; for the phenomena of propelling wheels and of projecting sealing wax filaments, occur whether the point be positively or negatively electrified. This is one of the difficulties *which the* advocates of the *plus* and *minus* states of electricity

have to contend with; for the phenomena of equal apparent emission from negatively electrified points appears to support the original hypothesis of Du Fay, that there are two distinct electric fluids. To account for the apparent anomaly, it is said that the effect of propulsion from the point fixed on the rubber, is not produced by the emission of negative fluid, but that it is caused by the mutual attractions always subsisting between bodies in opposite states of electricity. According to this view, therefore, the film of sealing wax is not projected from the point but it is attracted by the paper.

The seeming emission of air from points fixed on either of the conductors of the electrical machine is merely a secondary and a mechanical effect produced by the air being put in motion by the continuous discharges from the points.

The cause why points exert such powerful influence in the discharge of electricity has been explained by the researches of M. Coulomb into the distribution of electricity on the surfaces of bodies of different forms. On a sphere, every part of the surface being equally distant from the centre, the distribution of electricity is equal; but the more the shape of the body departs from that of a sphere, the more unequally is the electricity distributed. M. Coulomb insulated a metal rod, two inches in diameter and thirty inches long, with hemispherical ends; and having charged it with electricity, he found that at a distance of two inches from the end the electricity was to that in the middle of the rod as $1\frac{1}{4}$ to 1. At one inch from the end the proportion was as $1\frac{2}{3}$ to 1, and at the extreme end it was as $2\frac{3}{10}$ to 1. It appears from the results of his experiments that the intensity of the electrical charge increases in a very rapid proportion towards the edges of an insulated conductor; that it augments still more at the corners; and that when points project, their extremities concentrate the electricity with great additional intensity.

By the aid of these experiments, the cause of the escape or discharge of electricity from points may be readily inferred. The non-conducting air which surrounds an electrified body resists the escape of the electricity in proportion to its pressure on the surface, the amount of resistance being in an inverse ratio to the intensity of the electric force. If, therefore, the force be concentrated at a point where the amount of surface-resistance to its escape is reduced to the smallest quantity, the concentrated force meets with comparatively little obstruction, and rapidly rushes towards the surrounding bodies which are exerting an attractive power on the excited electricity.

One of the many effects of electrical induction is the distribu-

tion of static electricity entirely on the surfaces of conductors. As the electricity communicated to any substance induces an opposite state of electrical excitement on surrounding bodies, the mutually attractive influence draws all the electric fluid to the surface. Thus an insulated hollow ball, however thin its substance, will contain a charge of electricity equal to that of a solid ball of the same size, all the charge being distributed, in either case, on the surface alone. An experiment contrived by M. Biot affords a very satisfactory illustration of the distribution of electricity on surfaces.

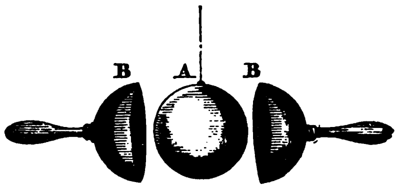


Fig. 18.

Let a metal globe, A, fig. 18, be suspended by a silken cord, and communicate to it a charge of electricity. Two hemispheres B, B, that will exactly enclose the globe, and insulated by glass handles, are placed over it when thus charged, so that the exterior surfaces of the hemispheres may become the outside of the globe. Under these circumstances, the whole charge of electricity will be transferred from the globe to the hemispheres; and when they are removed by the glass handles, all the electricity of the globe will be discharged, and will be retained on the exterior surfaces of the hemispheres.

The interior surfaces of hollow vessels have not any electricity distributed on them, because there is no opposing surface on which the electricity of the opposite kind can be induced. The inside of a hollow metal globe, for example, has opposed to it only the metal already charged with electricity of the same kind as its own; consequently, there can be no inductive action on such surface. The absence of electricity from the inside of charged metallic vessels may be shown by electrifying a metal ice-pail or a pewter pot placed on an insulating stand, and then lowering into it a metal ball suspended by silk, allowing it to touch the inside. When the ball is withdrawn, it will not indicate the least trace of electricity; but if it be then applied to the outside of the metal vessel, it will acquire and carry away a large portion of the charge.

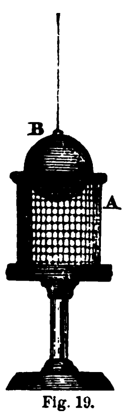


Fig. 19.

A more striking exemplification of the diffusion of electricity exclusively on the outsides of vessels is afforded when, instead of a

solid metallic vessel, a cylinder formed of wire-gauze is employed. Let the insulated ball B be lowered into the wire-gauze cylinder A, fig. 19, when electrified and mounted on an insulating stand. It may touch every part of the interior without receiving any portion of the electricity with which the exterior surface is charged, though the slightest touch on the other side of the open wire mesh communicates electricity to the ball.

Another experiment exhibiting the distribution of electricity on the surfaces of bodies is the following:—A net of thread is fixed to a metallic hoop mounted on an insulating handle as shown in figure 20, the lower part of the net being gathered round a small metal plate for the purpose of keeping it distended, and to facilitate the turning of the net inside out. When electricity is communicated to the net by lowering an insulated charged metallic ball inside till it touches the plate, the electricity, as in the former experiment, will be found on the outside only, and the interior will not retain any charge. If, whilst holding the insulating handle, the bag be turned inside out, as may be done by a dextrous movement, the electricity will be transferred to the other side of the net and be distributed still on the outer surface, though the sides have been changed.

Fig. 20

An experiment on a large scale was undertaken by Faraday,* which showed in a most conclusive manner that it is impossible to charge the interior of an insulated conducting body. He had a chamber constructed forming a cube of twelve feet. The outside was covered with a net-work of wire and with tin foil, and the whole was insulated in the lecture-room of the Royal Institution. A glass tube about six feet long was passed through the side of the chamber, leaving about four feet inside and two feet on the outside, and through the tube there was introduced a wire connected with the prime conductor of an electrical machine. "By working the machine," says Faraday, "the air in this chamber could be brought into what is considered a highly electrified state (being in fact the same state as that of the air of a room in which a powerful machine is in operation), and at the same time the outside of the insulated cube was everywhere strongly charged. But putting the chamber in communication with a discharging train, and working the machine so as to bring the air within to its utmost degree of charge, if I quickly cut off the connection with the machine,

and at the same moment, or instantly after, insulated the cube, the air within had not the least power to communicate a further charge to it. If any portion of the air was electrified it was accompanied by a corresponding opposite action within the tube, the whole effect being merely a case of *induction*. Every attempt to charge air bodily and independently, with the least portion of either electricity, entirely failed.

"I put a delicate electrometer within the cube and then charged the whole by an outside communication very strongly, for some time together; but neither during the charge nor after the discharge, did the electrometer, or the air within, show the least signs of electricity. I charged and discharged the whole arrangement in various ways, but in no case could I obtain the least indication of an absolute charge, or of one by induction in which the electricity of one kind had the smallest superiority over the other. I went into the cube and lived in it, and using lighted candles, electrometers, and all other tests of electrical states, *I could not find the least influence upon them, though all the time the outside of the tube was powerfully charged, and large sparks and flashes were darting off from every part of the outer surface.*"

The knowledge of the fact that electricity is distributed only on the surfaces of bodies has been applied to protect delicate electrometers from too violent action. A gauze cover placed over the instrument effectually prevents the gold leaves from being affected even when placed near to a powerful electrical machine.

By increasing the surface of any body charged with electricity the intensity is diminished. This was known to Dr. Franklin, who illustrated the absorbing influence of extended surface by electrifying a chain heaped together on an insulating stand, and then drawing part of it upwards by a silk thread. When the surface capable of being surrounded by "an electrical atmosphere" was thus increased, the intensity of the charge was diminished, and by lowering the chain again the original force was regained.

Another mode of showing the effect of enlarging the surface is to wind a strip of tin foil round a small insulated wooden cylinder, as represented in fig. 21. When a charge of electricity is given to the metal, the pith balls *a a* diverge. Take hold of the small piece of ribbon *b*, and draw some of the foil from the cylinder, so as to expose a larger surface, and the balls collapse. On winding the foil again on the cylinder the balls again diverge. The quantity of electricity can undergo no change by the altered state of the surfaces, but the intensity is *diminished* by the same quantity being diffused over a larger space.

The difference in effect produced by expanding or contracting the surface over which a given charge of electricity is diffused

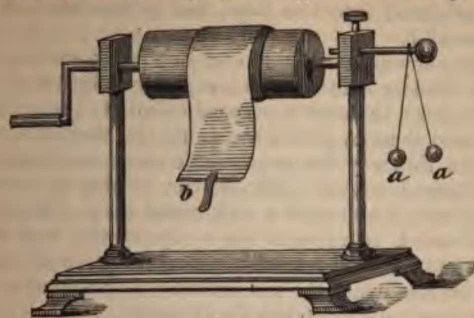


Fig. 21.

will be further noticed when we speak of the electrical battery.

Though the electrical charge resides on the surfaces of conductors, it does not, in fact, exist as an atmosphere of electricity around them, as was formerly imagined, but it seems to be confined within the external surface. For instance, there is no difference in the distribution of electricity on metals when a part or the whole surface is covered with varnish, or even with a thick coat of wax.

The electricity excited by the electrical machine is in a high state of intensity, but the quantity is comparatively small. Yet the concentrated energy of that small quantity enables it to force a passage through the non-conducting air to a greater distance than when collected in much larger quantities in a lower state of intensity. The physical effects of the long spark emitted from the machine are only feeble. They are sufficient, however, to show the igniting power of electricity in some of the more inflammable substances. If spirits of wine be warmed in a metal spoon, and a spark from the conductor be made to pass through the spirit, it will be instantly set on fire. This experiment appears the more curious when the spark is passed from the finger of a person placed on an insulating stool.

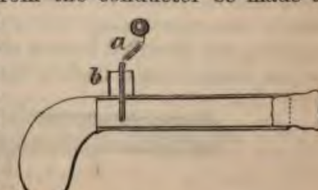


Fig. 22.

Hydrogen gas, as previously stated, may also be inflamed by a spark. For performing this experiment in the most efficient manner, an electrical cannon or pistol is constructed. It consists of a brass tube, about one

inch in diameter and six inches long, closed at one end. A piece of wire *a*, fig. 22, that is to conduct the electricity through the gas, is introduced into the tube, but is insulated from it by ivory or wood, *b*.

The most convenient way of charging the pistol is to attach a tube to a bladder containing an explosive mixture of hydrogen and oxygen gases, to insert it perpendicularly to the farther end of the pistol, and then, by gently squeezing the bladder, to force the gas out. In this way the atmospheric air is displaced, and the pistol is charged without wetting the insulating ivory. The open end is then closed with a cork whilst the pistol continues to be held inverted, to prevent the escape of the hydrogen. On taking a spark from the machine through the wire, by holding the pistol in the hand, the gas explodes with a loud report, and propels the cork to a considerable distance.

In charging the pistol in this manner from a bladder filled with an explosive mixture of hydrogen gas, care should be taken not to allow a lighted candle to be brought near. From neglect of this precaution on one occasion, an accident happened to the author that produced considerable alarm. He was filling a gun-barrel with explosive gas from a bladder held under his arm, when, in consequence of approaching too close to the candle, the contents of the bladder exploded, extinguishing the lights and stunning his arm and side, though it did no serious damage.

The resistance offered by air to the passage of electricity may be very beautifully illustrated by sparks from the machine. If the air were a conductor there could be no manifestation of electrical phenomena, for the equilibrium would be restored as quickly as it was disturbed; but the resistance of the air serves to retain the excited electricity on the surfaces of electrified bodies. When the electricity possesses sufficient intensity to force its way through the resisting air, the discharge is accompanied by a bright spark. If the machine be powerful and in good order, sparks three or four inches long may be obtained, which, in overcoming the resistance of the non-conducting medium, are diverted from a straight path and describe a ziz-zag course, resembling a flash of forked lightning.

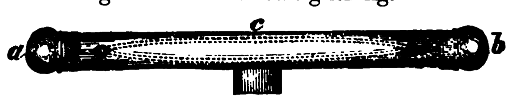


Fig. 23.

That the resistance to the passage of electricity from body to body is caused by something more than by the intervening space, *is proved by the* facility with which electrical discharge is effected

through vessels exhausted of air. For instance, let a glass tube, C, fig. 23, about three inches in diameter and two feet long, be fitted at each end with a brass cap, to which a wire and a brass ball are attached that reach two or three inches inside. At one end there should be a screw to fit on to the air-pump, by which the tube may be exhausted. On applying the exhausted tube to the prime conductor, and the machine is put in action, the electricity passes readily through the partial vacuum. When the experiment is performed in the dark, the interior of the tube will be observed to be luminous with beautiful purple-coloured flashes, which present a miniature resemblance to the aurora borealis.

If the air be gradually admitted whilst the machine continues in action, and the tube be removed a short distance from the conductor, so that sparks may pass between it and the brass cap, the resistance to the electricity will increase as the air is admitted, until the sparks can no longer force a passage. At an early stage of the re-admission, when the air is still greatly attenuated, the electric spark will pass through like a ball of light, moving comparatively slowly, so that its form and course may be distinguished. This very interesting experiment, which requires a little address for its perfect development, exemplifies the phenomena of meteors or "falling stars" in the upper regions of the atmosphere, where the air is less rarefied than in the higher fields of space where the aurora coruscates.

Faraday has examined with much care the various kinds of electrical discharge, with a view to establish his theory of induction; and he has succeeded in accumulating a great number of interesting facts connected with the transmission of electricity through resisting media. His theory of induction, as we have before stated, supposes that the particles of non-conducting bodies, when acted on by an electric force, assume a polar state, and form a chain of contiguous particles, each one of which has a positive and negative end. This polarized chain of particles, it is assumed, extends from the excited electric through the air or other non-conducting body, and induces in the nearest conducting body a state of electricity opposite to that of the coercing force. In proportion as the particles of different substances possess the power of communicating electricity to each other, their tendency to assume a polar condition diminishes; and, on the other hand, the greater the non-conducting property of the particles, the more strongly will they take the polar direction. In other words, induction can only take place across insulating substances, *and the inductive action is more or less readily assumed according to the power of conducting* electricity.

Applying this theory to the explanation of electric discharge through resisting media, Faraday assumes that there is a limit to the influence which the intervening chain of polarized particles possesses in retaining the attracting forces apart, and that when any of the contiguous particles have attained their highest degree of polarized exaltation, they can no longer resist the passage of the electric force. Thus when one or more links of the chain are subverted, the two forces cannot be restrained. Every case of discharge is therefore preceded by inductive action which coerces the insulating particles into a polar state, until they are restored to their natural condition by the overpowering attraction of the combining forces.

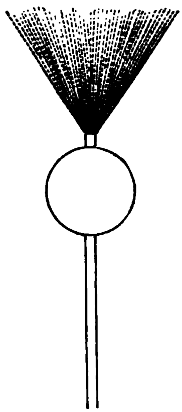


Fig. 24.

The electric spark is considered "as a discharge or lowering of the polarized inductive state of many dielectric particles by a particular action of a few of the particles occupying a very small and limited space, all the previously polarized particles returning to their first or normal condition in the inverse order in which they left it, and uniting their powers meanwhile to produce, or rather to continue, the discharge effect in the place where the subversion of force first occurred."*

The sudden restoration of the electrical equilibrium by the mutually attracting forces bursting through the intervening non-conducting space, is termed *disruptive discharge*. It may take place either in the form of a spark or in a series of rapidly-intermitting discharges, so near together as to appear continuous. The latter is called the *brush discharge* (fig. 24), from the form of its luminous coruscations.

To produce the brush discharge with effect requires the machine to be in good order, and the intensity of the electricity on the prime conductor to be increased by adding to it a projecting rod with a small rounded end. The discharge takes place from the end into the air, or to any conducting body brought near, and it is accompanied with a continuous rushing noise. Professor Wheatstone has proved that the sound is produced by a rapid succession of disruptive discharges, and that the brush of light observable in a darkened room is resolvable into a number of brushes, each one of which indicates a separate and instantaneous discharge; though the discharges

* *Experimental Researches.*

are so rapid as to mingle together in one luminous expanding cone, with a bright apex near the discharging conductor.

The difference in the appearance of the brush discharge from the positive and negative conductors is very observable. The brushes obtained from the negatively charged conductor (fig. 25) are shorter, and the discharges are more rapid, "being seven or eight times more numerous in the same period than those produced when the rod was charged positively to an equal degree."

Fig. 25.

Another form of discharge is obtained when a fine point, instead of a blunted thick wire, is attached to the prime conductor. In that case, a smaller pencil of rays, which produces a steady light, takes the place of the expanding brush and rushing sound. This has obtained the name of the *glow discharge*, *a*, fig. 26. It is probable that even this steady and noiseless discharge might be resolved, like that of the brush, into an innumerable quantity of intermittent discharges, mingled together so intimately as to be separately indistinguishable.

When a fine point is attached to the insulated rubber of the machine, the light of the negative electricity presents the form of a star, *b*.

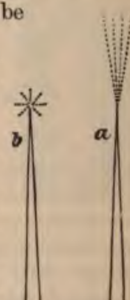


Fig. 26.

The light of the electric spark varies as it passes through different media. In air the sparks have an intense white light tinged with blue, and parts of the track of light they form appear frequently to vary in intensity, especially when the quantity excited is not great. In nitrogen gas the sparks are more deeply coloured with blue or purple, and Faraday considers them remarkably sonorous. In hydrogen, the colour is crimson; in oxygen, whiter than in nitrogen, and not so brilliant; in carbonic acid gas the appearance is nearly similar to that in air, but with a green tinge, and remarkably irregular; in coal gas the spark is sometimes green, sometimes red, occasionally one part green and another red, and the dark parts occur very suddenly. These various colours of the spark in different gases are considered by Faraday to be attributable "to a direct relation of the electric powers of the particles of the dielectric through which the discharge occurs, and are not the mere results of a casual ignition, or a secondary kind of action of the electricity upon the particles which it finds in its course, and thrusts aside in its passage."*

* *Experimental Researches.*

The brush discharge also exhibits peculiar characters in the different gases; the effect in nitrogen being finer in form, light, and colour than in any other gas, and it evolves a greater quantity of light. The peculiar character of nitrogen in relation to the electric discharge must, it is supposed by Faraday, have an important influence over the form and even the occurrence of lightning, as that gas, which extends the discharge of electricity farther than any other, constitutes four-fifths of the atmosphere.

CHAPTER IV.

ACCUMULATED ELECTRICITY.

The Leyden jar—Its construction and mode of action—One jar charged by electricity escaping from another—Chain of Leyden jars self-charged—The charge in the glass, and not in the coating—Charged plate of glass—Electrical batteries—Intensity of force diminished by extension of surface—Discharging-rod—Residual charge—Lateral discharge: its cause and effects—Universal discharger—Lane's discharger—Quadrant electrometer.

Fig. 27.

THE power of accumulating electricity by means of the Leyden jar has placed in the hands of electricians a force of almost unlimited extent. In our sketch of the history of electric science, we have already adverted to the nature of the apparatus. As at present constructed, it consists of a thin glass jar A, fig. 27, coated within and without with tin foil, which coating reaches to about three inches of the top. A wooden cover B, serves as a support to a straight thick brass wire C, that passes through the centre of the cover, and has a metallic connection by a chain or wire with the interior coating. The thick wire rises a few inches above the cover, and is surmounted by a hollow brass ball, which is screwed on to the top of it, the object of the ball being to prevent the dispersion of the electricity. The sizes of the jars vary from half-a-pint to ten gallons. A jar holding a pint will give a shock as strong as most persons like to receive.

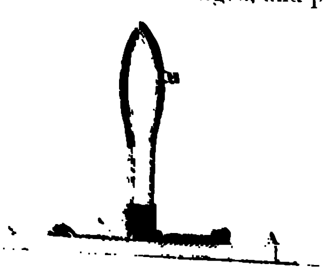
To charge a jar with positive electricity, bring the brass ball near to the prime conductor of the machine, and make a connection between the outside coating and the ground. When fully charged, it will give indications of its electrical condition by a muttering sound; and in the dark, rays of light will be seen issuing from the edges of the tin foil and from the ball.

The notion of Muschenbrœck, which led to the discovery of the Leyden jar, was to collect electricity within a phial to prevent its dispersion, and thereby to store up an increased quantity of the electric fluid; but the present received opinion is that a jar when highly charged does not contain more electricity than it did before it was applied to the conductor. The effect produced by charging *is not* to increase the quantity, but o

alter the condition of the natural electricity previously present in a latent state on the inside and outside of the glass. There is injected into the inside, by connection with the electrical machine, an amount of positive electricity, whilst an equal amount of negative electricity is driven from the outside by the force of electrical induction; and unless the electricity on the outer surface of the glass can be thus driven off by affording it a connection with the ground, the inside cannot receive a charge.

The cause of the accumulation of electricity in the Leyden jar has been already stated to depend on inductive action operating through the substance of the non-conducting glass. It has been shown that a pane of glass when excited by friction on one side, has negative electricity induced on the other, and that a glass tumbler may be charged with electricity by exposing the inside to the influence of an electrified point, whilst the outside is grasped by the hand. The electricity thus collected on the surfaces of the pane of glass and the tumbler is sluggish in its motion, and is dissipated by slow degrees, on account of the non-conducting property of the glass surfaces; but if metal plates be pressed on each side of the pane of glass, the electricity is instantly concentrated at any point, and on connecting the two surfaces with a wire, a discharge takes place, exactly as in the Leyden jar. The charged tumbler might also be converted into a Leyden jar by the application of interior and exterior casings of metal [illegible] serve as non-conductors, to concentrate at any point [illegible] distributed over the surface of the glass.

[illegible] most conclusively that the charge of a Leyden jar is [illegible] the surface of the glass, and not in the metallic [illegible] Leyden jars are made with inside and outside metallic [illegible] contrived that they may be easily removed. A jar [illegible] when charged, and placed on an insulating stand, may have the metal casings removed and others substituted for them; yet after this change the jar will be found to retain its charge. The metal serves only to conduct the electricity simultaneously from all parts of the glass with which it is in contact.



A plate of glass affords the most convenient mode [illegible] the electrical charge is retained by the glass [illegible] Let a pane of glass A A, fig. 28, about one

foot square, be laid horizontally on a sheet of tin foil. To the upper side apply the insulated metal disc C of an electrophorus; connect the disc with the prime conductor, and a few turns of the machine will charge the glass. Remove the disc by the insulating handle B, and it will manifest scarcely any trace of electricity. Let the same or another disc be again applied to the surface of the glass, and on making connection between the metals on the opposite sides a strong discharge will take place. To make the experiment still more striking, the tin foil on which the plate of glass is placed may be withdrawn and the glass be lifted up by its edges and laid on another sheet of metal without losing its electrical charge, for the insulated disc being again applied, a powerful discharge will occur when the two metallic surfaces are connected by a wire.

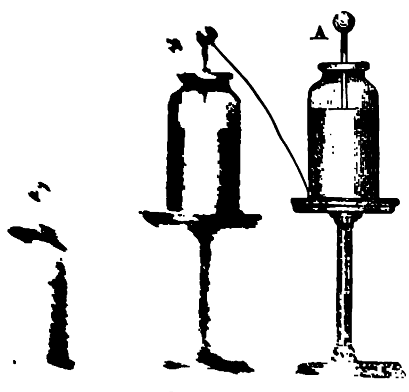
Let a Leyden jar be insulated from the earth by placing it on a glass stand, and it will receive scarcely any electricity from the conductor; not more than equal to the quantity which can escape from the outside to the surrounding air. If the knob of another insulated jar be connected with the ground, and the outside coatings of the two jars be brought near together, sparks will then pass rapidly from the prime conductor to the knob of the first, and they will also pass as rapidly between the outside coatings of the two jars. In this manner both the Leyden jars become charged, and it will be found that they are charged equally, but with electricity of opposite kinds. The first one that derives its electricity directly from the prime conductor is charged positively; the second that becomes in an electrical condition by parting with its natural electricity from the knob to the ground, will be negative. Place the two jars on the table, and suspend between them a pith ball B, or other light substance, and it will be attracted alternately from one to the other in rapid vibrations, clearly showing that the electricity in the two jars is of opposite kinds. In this manner both jars will be discharged by the continued transfer of the opposite kinds of electricity from one to the other by the pith ball.

Fig. 29.

The phenomena that occur during the charge of a Leyden jar have been adduced as strong evidence in support of the

Franklinian theory of a single electric fluid. The discharge of electricity from the outside in proportion to the charge received within leaves the outer coating in a negative or *minus* state, whilst the interior receives more than its natural quantity. On making a metallic communication between the two coatings the balance is immediately restored, with the loud snap and brilliant flash that accompany sudden disruptive discharge. But the phenomena are explicable also on the hypothesis of two fluids; it being assumed that they are separated from their previously neutral state by the coercing force of the free electricity communicated to the inside of the jar. The fact that the electricity driven off from the outside coating is positive is explained on this hypothesis by supposing that the natural electricity of the outer coating is decomposed or separated by the positive electricity entering the jar, and that the positive electricity from the outside passes off to the ground, whilst the negative electricity, with which it was combined, is disguised on the outer coating.

Franklin attempted practically to apply the charging of one jar from the escaping electricity of another, so as to charge many jars at the same time with the overflow from one to the other. He inferred that if a series of insulated jars were arranged with the outside coatings and knobs alternately touching, the coating of the last one being connected with the ground, that by this arrangement the positive electricity expelled from the outside of the first would charge the second; that the electricity from the outside of the second would charge the third positively, and so on to any number; and that an immense electric force might be thus accumulated from the same quantity of electricity that is required to charge a single jar.



Let A B C represent a series of three jars, A and B being mounted on insulating glass stands. On making connection from the prime conductor of an electrical machine to the knob of A, that [illegible] an equal amount of electricity [illegible] into B, which will also be posi-

ely charged. The third jar C, will in like manner be charged m the outside of B, and the electricity which was expelled m A, on arriving at the outside of the last jar of the series, will conducted to the earth.

If a metallic connection be made from the knob of B to the ob of A, there will be a discharge of the first jar only; for ough the connection is made with the knob of B, none of the sitive electricity within that jar can be discharged, for it is trained by the coercing force of the opposite electricity on the tside. Making connection between the knob of B and the ob of A is indeed only the same as making connection between latter and the outside coating of A with which B is concted. If whilst the jars remain on their stands metallic conction be made between the outside of B and the knob of A, th those jars will be discharged, and the third will remain arged; but by bringing a wire from the outside of C to the ob of A, the three jars will be at once discharged. The cumuive discharge of the three jars, however, would have no greater

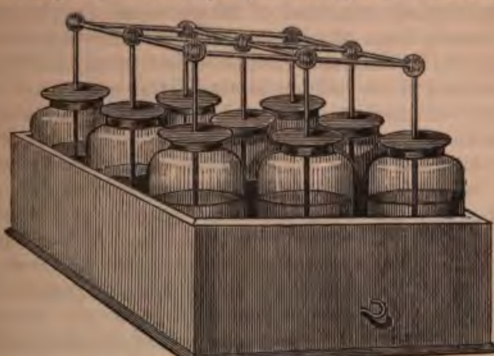


Fig. 31.

ect than the discharge of a single one. All the electricity ought into action is but the quantity thrown into, and colted by, the first jar, for it passes from the inside of one to the tside of the other in succession. But if the jars when charged taken from the insulating stands, their outside coatings being nnected together, and the knobs also united, on then making nnection between the inside and outside coatings of any one, three will be discharged at once, and the electrical effect ll be three times greater than the discharge of a single jar.

It is by an arrangement of Leyden jars similar to the
ntioned that charges are accumulated for exhibiting

powerful effects of electricity excited by friction. A combination of this kind is called an electrical battery. For convenience, the jars are placed in a box with divisions, the bottom being lined with tin foil, to make connection with all the exterior coatings. The knobs of the jars are connected together by wires, as represented in fig. 31; and there is a metal hook projecting from the side of the box connected with the tin foil lining. Thus all the interior and all the outside coatings of the jars are connected: and when communication is made between the prime conductor and any of the knobs of the jars, the whole are simultaneously charged. They are also discharged simultaneously by making connection between the projecting hook and any one of the knobs. The combination of several small jars is found better than a smaller number of large ones, because the thickness of the glass necessary in jars of large size obstructs induction through it. By an arrangement of many jars an amount of electric force may be accumulated that almost equals the destructive power of lightning. The battery used by Faraday in his experiments consisted of fifteen equal jars, coated eight inches upwards from the bottom, and twenty-three inches in circumference; so that each contained 184 square inches of glass coated on both sides, independently of the bottoms of the jars, which were of thicker glass, and contained each about fifty square inches. The total coated surface of the battery consequently comprised 3,500 square inches of coated surface. The electrical battery at the Polytechnic Institution exposes a coated surface of nearly eighty square feet. To receive the full charge of such a battery would be instant death. A battery of nine quart jars is sufficient to exhibit the deflagrating effects of electricity on a small scale; nor would it be safe to receive a shock from a battery of that size.

It is a fact deserving consideration that the accumulation of quantity diminishes the intensity of electricity. For instance, an ordinary electrical machine when in good action will emit sparks three inches long. When a single Leyden jar is charged with twelve such sparks, the accumulated electricity will not force its passage through more than a quarter of an inch; and if the same quantity be distributed among the jars of an electrical battery, the discharge will not take place through the eighth of an inch. The quantity of electricity in the latter instance is the same, but the state of intensity diminishes in proportion to the surface over which it is diffused. The difference between quantity and intensity is still more remarkably manifested in the different conditions of frictional and voltaic electricity, as will be subsequently noticed.

One of the peculiar phenomena of the electrical battery is the *residual charge.* When communication is made between the inside and outside coatings of a battery consisting of several jars, the whole of the electricity is not immediately discharged. On again making connection between the inside and outside coatings, after a short interval, a second discharge will occur; which, though comparatively feeble, might occasion a disagreeable shock. The cause of this residual charge is partly attributable to the accumulation of electricity on those parts of the jar just above the metallic coating; which portions, not being in direct contact with the metal, are not conducted with equal rapidity. Part of the charge also is contained in the interstices of the glass, and is thus removed from immediate contact with the metal.

The simplest kind of instrument employed for discharging a Leyden jar or an electrical battery is a thick curved piece of brass wire, fitted with a small ball at each end. One of these balls is applied to the outside coating, and when the other is brought near to the knob of the jar, the electricity instantly passes through the wire with a smart snap or report, connection being thus made between the two charged surfaces of the jar. When, however, a discharger of this kind is employed for an electrical battery a slight shock is felt, owing to what is termed the *lateral discharge;* therefore, to avoid the inconvenience and the danger that might arise from holding the wire in the hand, an insulated wire is generally employed. Its form is represented in fig. 32, as applied in discharging a Leyden jar. Two thick brass wires, *a a*, of equal lengths, and terminated with brass balls, are jointed together at *c* for the convenience of adjustment, and are cemented to a glass handle, *b*, which serves to insulate the wires from the hand, and prevents the liability of any perceptible portion of the charge being received by the operator.

Fig. 32.

There has been much discussion among electricians on the subject of lateral discharge, in reference more particularly to the safety of lightning-conductors; we shall therefore briefly notice in this place the cause of the phenomenon.

It is the case with electricity, even to a greater extent than with all fluid bodies, that it will discharge itself into every channel that is open to it. Thus, as in a mountain torrent some portion of the water will deviate from the straight and broad course into circuitous and narrow crevices, so will the highly tensive electric fluid force its passage through every conducting medium, even though the course directly open to it appears to offer a free passage. It must be borne in mind, however, that as every water-course offers some obstruction to the current, so does even the best conductor offer resistance to the electric fluid; some portion of which is consequently diverted through every conducting substance by which it can be transmitted. Thus, when a Leyden jar is discharged with a wire not insulated, a small part of the charge passes through the circuitous and comparatively obstructive course offered by the body of the operator, by the floor, and by the table whereon the jar is placed. In the case of a single jar, the quantity of electricity that passes in that direction is imperceptibly small; but when several jars are combined, the lateral discharge may become unpleasantly strong, especially if the wire of the discharging-rod be not very thick. Even when an insulating discharging-rod is employed, we may infer that some portion of electricity will force its way along the glass; but it is so infinitesimally small as to be inappreciable.

Applying the experience and inferences deducible from experiments with the electrical battery to the more powerful effects of lightning, we are led to consider that every flash of lightning must be accompanied by lateral discharge, and that the quantity thus diverted from the direct and easiest path between the clouds and the earth will depend on the amount of resistance which that direct course offers. Therefore, though lateral discharge must, to some extent, always occur, it may be rendered entirely innocuous by a sufficiently thick and unbroken lightning-conductor. In the Report of a Committee appointed by the House of Commons to examine the plan proposed by Sir William Snow Harris for protecting ships from lightning, several eminent scientific men expressed their opinions that no lateral discharge could occur with uninterrupted conductors of sufficient thickness. These opinions, however, could only have had reference to any possible danger likely to arise from the division of the charge in other directions; for it has been satisfactorily proved that during an electric discharge and the transmission of an electric current, some portions are diverted into every possible path.

Reverting to the consideration of the electrical battery and

the apparatus connected with its application, we must notice particularly the "universal discharger" as an instrument of very general utility in electrical experiments. It consists of a wooden base A, fig. 33, into which are inserted three upright pillars. The two outermost pillars are of glass, for the purpose of in-

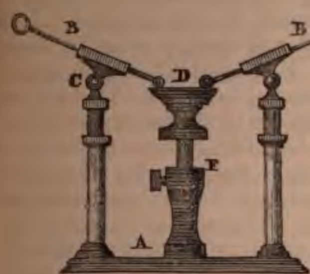


Fig. 33.

Fig. 34.

sulating the ball-and-socket joints C C, through which brass rods B B slide, so as to bring them to any required distance on the small table D, which is supported on the central pillar E. The table may be raised or lowered by the slide E, and fixed by a screw. The outer coating of the Leyden jar or battery is connected with one of the rods, and the insulated discharger being connected with the other by means of a chain, the charge of the battery is thus very conveniently sent through any substance placed on the table between the ends of the two rods.

Lane's discharger is frequently very useful in connection with the preceding instrument, as it is self-acting, and transmits a succession of charges of regulated power. Fig. 34 will afford a correct idea of the construction of this apparatus. A bent glass rod C is attached to the wire of a Leyden jar, and on the top of the bent arm is a brass ball with a hole in it through which the horizontal wire D slides, so as to regulate the small ball at the end of it to any required distance from the knob of the jar. A wire or chain E connects the horizontal wire with the outside of the jar; and in its course may be placed the universal discharger or any substance to be operated on. It is evident from this arrangement that the discharge of the Leyden jar will take place whenever the electricity has att[illegible] a degree of inten[illegible] [illegible]ficient to overcome the resistance

air in the space between the knob of the jar and the ball of the discharger; and by the proper regulation of that distance a succession of charges of nearly equal strength may be transmitted without any interference with the apparatus. This kind of discharger is sometimes attached to the prime conductor of the electrical machine as a more convenient mode of appliance.

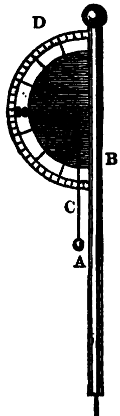


Fig. 35.

For ascertaining the intensity of charge, an instrument constructed on the principle of the pith-ball electrometer is usually attached to the prime conductor. It is called Leslie's quadrant electrometer, represented in fig. 35. The pith ball A, attached to a light but rigid stem C, is suspended from the upright conducting pillar B, and is repelled proportionally to the intensity of the electricity in the Leyden jar or battery connected with the prime conductor. The quadrant D is graduated to mark the degree of repulsion, and by this means, and with the aid of Lane's discharger, the intensity of any charge or succession of charges may be known and regulated.

CHAPTER V.

MISCELLANEOUS PROPERTIES AND EFFECTS.

The electric shock: its physiological effects—Application of electricity as a curative—Experiments on living animals—Heating power of the electrical battery—All electrical effects consequent on resistance—Illustrative experiments: broken glass, thunder-house, piercing holes through card, firing gunpowder—The electric light: instantaneous duration of the spark calculated—Magnetizing and decomposing power of static electricity—Chemical decomposition.

NEARLY all the properties of accumulated electricity may be exemplified by means of a cylinder machine of nine inches diameter and a battery of nine quart jars, assisted with the accompanying apparatus which we have described. Many of the phenomena we are about to notice require only a single jar for their development.

The sudden contraction of the muscles by the peculiar action of electricity on the nerves is at all times startling and disagreeable, and when the sensation of the shock was quite novel, and the consequences unknown, the dread that it occasioned was perfectly natural, though the exaggerated accounts first given of the effects seem now to be ridiculous. We have already noticed the remarkable effect of a charge sent through the brain, as described by Dr. Franklin in his dangerous-seeming experiments: but without venturing on such powerful charges as he distributed without fear, the sudden loss of muscular power may be proved without danger by sending a comparatively small shock from a single jar through the spine. When a powerful charge is sent through the lungs it is said to cause a violent shout; and a much smaller charge through the same organ occasions involuntary laughter. The derangement of the nerves by the sudden shock has the effect of causing, in nervous persons, continued trembling of the limbs for some time afterwards; and a frequent repetition of electric shocks is by no means desirable.

When the powerful influence exerted by electricity on the nervous system was discovered, great hopes were entertained that it would prove a valuable remedial agent. These hopes have, however, for the most part been disappointed. Several instances, indeed, are recorded of wonderful cures effected b*y electrical agency*, though they seem to have been more depen

on the imagination than on the direct influence of electricity. In cases of chronic rheumatism rapid successions of feeble electric shocks or vibrations have been found to afford relief; but generally speaking, the application of electricity to medical purposes has hitherto failed of success, probably from ignorance of the means by which its powers may be rendered serviceable.

Of the experiments made on living creatures with a view to ascertain the amount of charge sufficient to produce death, those on eels are the most curious. Difficult as it is to deprive them of life by ordinary means, they are killed instantly by a powerful electric charge; and when such a charge is sent through a part only of the body of an eel, that portion is deprived of life, while the other part continues to exhibit signs of vitality. It has been observed that the bodies of animals killed by electricity very quickly decompose; and this fact seems to explain what Franklin was inclined to conceive a mere "fancy," when he thought that a turkey killed by electricity ate remarkably tender.

The fusing effects of electricity were known before it was acknowledged to possess the property of imparting heat; and some of the early electricians entertained the notion that the deflagration of thin leaves of metal by the electrical battery was produced by what was termed "cold fusion."

Some illustrations of the igniting power of the electric spark have been already mentioned; but to exhibit the heating effects of electricity on metals, and on other less inflammable substances, requires an electrical battery containing a considerable amount of coated surface.

Let a thin strip of gold, silver, or copper leaf be attached by moisture between the rods of the universal discharger, and connect one of the rods with the outside coatings of the battery-jars. When the battery is fully charged, as indicated by the elevation of the ball of the quadrant electrometer, apply one of the knobs of the insulated discharging-rod to the second rod of the universal discharger, and bring the other knob of the discharger in connection with one of the knobs of the battery-jars. The charge will thus be sent through the strip of metal leaf, which will be instantly deflagrated. If the metal leaf be laid upon paper, the part whereon it was placed will be scorched, and traces of metallic oxide will remain. A small length of very fine wire may be deflagrated in the same manner.

The deflagration of the metal leaf and of the wire are caused by the resistance which such a small thickness of metal offers to the passage of the electric charge; for if they be a little *thicker*, so as to allow the electricity to pass more freely, the *metals will* be made red hot without being melted. It is,

, in all cases of electrical action, only by the resistance offer to the passage of accumulated electricity that its ce is manifested. Through metals sufficiently thick to t it freely, electricity passes without any sign; but a charge sent through an imperfect conductor may pro- lestructive effects, in consequence of the resistance it ters. This observation applies to all electric action what- provided the resistance be not so great as to prevent the rge. *The manifestation of electricity is a proof of resis- offered to its passage; and when the resistance is decreased trical effects are diminished.*

following experiment affords a satisfactory illustration of crease of effect by increasing the resistance. Paste a strip of tin foil across a small piece of sheet glass; on the it place a corresponding piece of glass, perfectly dry, and both together with a weight. The charge of a battery hus be sent through the tin foil without any perceptible Cut away a small part of the foil, so as to leave a break middle about the sixteenth of an inch. The battery may even then be sent between the glasses without but the electricity will manifest itself by a bright spark point of separation in the foil. Increase the interval by away another portion of the foil, so that the resistance electric fluid may be increased, and on then repeating charge the glass will be shivered.

apparatus called a "thunder-house," constructed for the e of showing the action of ng - conductors, illustrates atisfactorily the effect of in- d resistance to the course of ctric discharge. A piece of any about an inch thick is into the form of the gable a house, A fig. 36; and there all square wooden shutter D, nay be easily taken out and at opposite corners. A wire B C, rises above the y, passes down the house and he shutter to the hook C, that ected with the outside of a eyden jar. When the jar is ged through the wire, in the

Fig. 36.

represented in the diagram, the shutter retains its *electric circuit is not* interrupted; but if the s

turned, so that the wire may be in the direction marked by the dotted lines, the continuous circuit is broken, and the resistance which the electric fluid meets with in crossing the intervening space causes the shutter to be forced out to some distance.

Another and very simple illustration of the effect of increasing the resistance to the passage of electricity during disruptive discharge, is afforded by sending the charge of a Leyden jar through a card, when it is moistened and when it is dry. When a moistened card is interposed between the discharger and the coating of the jar, no perceptible effect is produced, because the moisture operates as a sufficient conductor to diminish the resistance. Let the same amount of charge be then sent through a dry card, and a hole will be made in it of the size of a large pin hole. On looking closely at the hole thus made, a burr will be observed raised on each side of the card, as if the penetrating force had operated from the centre outwards, in opposite directions. In all other cases of the exhibition of electrical force in which the direction of it can be distinguished, the same appearance is observable, the disruptive action seeming to be always exerted in opposite ways.

The discharge of a Leyden jar may be prolonged by interposing an imperfect conductor; and by thus diminishing the rapidity of the passage of the electric fluid, it will produce effects that its more rapid action renders unattainable. Thus, if a small quantity of gunpowder be laid on the table of the universal discharger, the effects of an ordinary discharge will disperse the powder without igniting it; but if the metallic circuit be interrupted by a basin of water interposed between two ends of the connecting wires, or if a wetted string form part of the circuit, the discharge is prolonged by the increased resistance, and the force, though less energetic, is more effectual in igniting the gunpowder, which then explodes instead of being dispersed.

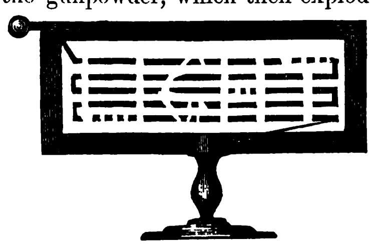


Fig. 37.

Several forms of apparatus have been contrived for exhibiting the electric light. Spangles of tin foil are pasted on to glass in various patterns, so arranged as to form an interrupted line for the passage of the electric fluid. By means of Lane's discharger, a continuous stream of small charges is sent through these breaks in the conducting metal foil, at each of which a brilliant *spark appears*, representing in vivid lines the device arranged by

disposition of the breaks in the foil. In the dark this bition has a very beautiful effect; and when a lengthy ce is patterned on the glass, the simultaneous appearance arks at all the breaks serves to show in some degree, the ntaneous character of the electric discharge.

e simplest form of apparatus of this kind is a tube about two s diameter, with circular pieces of tin foil pasted in a spiral d it, from the top to the bottom, the upper part being red with a brass cap, as shown in fig. 38. When this is held in the hand and presented to the prime con- or of an electrical machine, brilliant sparks pass ntaneously between the spirally disposed spangles. times several of these tubes are mounted on a stand, are made to support a glass cupola which is also led with spangles. With an electrical machine in working condition, this little glass structure may be antly illuminated, and will look like a miniature fairy le of light. In other devices continuous strips of tin re pasted on a sheet of glass, and words or patterns are ut, as on figure 37 (see p. 106), which become luminous succession of discharges from a Leyden jar, or by hold- he brass knob with which the metal foil is connected at a distance from the conductor of the electrical machine. In rrangement of the tin foil spangles in devices, care must be that the sum of the spaces between each is not greater the space through which the electricity of the jar will arge itself. Sparks from the prime conductor of the ric machine will traverse over a much greater space than a arge from a Leyden jar, but the light is not so intense. spended chain also serves to exhibit the brilliancy and ntaneous nature of the electric discharge. Vivid sparks ar at the junctions of the numerous links; and the chain is hung in festoons, beautiful luminous ry is produced.

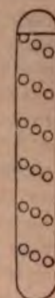


Fig. 38.

e diamond jar affords another beautiful illustra- of the light of the electric spark. The internal external coatings of a Leyden jar, are composed of mber of diamond shaped pieces of tin foil, pasted their angles at a small distance apart from each . When a jar of this kind is charged in the dark, ations of light will be seen proceeding from each e points of separation, both in the inside and on the outside, e positive electricity enters the jar and the negative electri- *scapes from the outside.* On discharging the jar in t *er, very brilliant* sparks will be seen between all

Fig. 39.

The instantaneous duration of the electric spark has been shown in a striking manner by a very ingenious application, by Professor Wheatstone, of one of the properties of vision. The retina of the eye, it is well known, possesses the peculiar property of retaining the impression of an image for the eighth part of a second after the object that produced it is removed. The eighth part of a second may perhaps seem to most persons a duration inappreciably small; but those accustomed to note time will detect with the naked eye, a variation of the tenth part of a second in the vibration of a pendulum, and by means of the copying electric telegraph a variation of the thousandth part of a second may be detected and rendered visible. It is owing to the duration of the impressions on the retina that a lighted stick, when moved rapidly in a circle, appears like a circle of light, for there is a continual renewal of the impressions on the retina by the light from a similar position before the former impressions are extinguished. Were it not for the retention of images by the retina, the line of light would appear to be broken, and the different positions of the lighted stick would be indicated by separate sparks. It is owing also to the duration of impressions on the retina that a circular screen containing figures or patterns painted on it becomes a confused mass of colour when turned rapidly round.

It may be easily conceived, however, that if only *instantaneous* sight could be obtained of either of the whirling bodies, it would be seen in its true form; that is, the lighted stick would appear as a stationary spark, and the figures on the screen would be distinctly visible, and would seem to be stationary, though in reality revolving very rapidly. It is by applying this principle that the duration of the electric spark may be determined. A painted screen is turned round rapidly in the dark, and is lighted at intervals by electric sparks from a Leyden jar. The figures on the screen seen by this occasional light appear quite distinct, and to be at rest. The velocity of the screen's motion is regulated to a known number of revolutions in a second, and by increasing the rapidity a speed is at length attained at which the colours become confused; even the instantaneous duration of the electric spark affording time for the objects to be seen in more than one position. The rapidity of revolution being known, and also the duration of impressions on the retina, the length of time that light is thrown on the screen just before the figures become confused may be estimated. Professor Wheatstone has ascertained that the duration of the electric spark is not longer than the millionth part of a second.

The electric spark seems, indeed, to be much longer in sight;

the retention of the impression by the eye causes the dura- of the light to remain for the eighth part of a second, gh the light itself only lasts the millionth part of that time. sh of lightning is equally instantaneous, and all objects in on seen in the night-time by lightning appear to be at rest. a cannon ball in rapid flight would appear to be motionless e air. "As quick as lightning" has become a proverbial ssion, though few persons are aware how very instantaneous lly is.

nong the remarkable properties of electricity, its magnet- and decomposing powers deserve to be especially mentioned. will be noticed more particularly when we speak of that fication of the force exhibited in the voltaic battery; but a examples of the exercise of those powers by statical elec- y will serve to show that in these, as in all other respects, is a close resemblance between the chemically excited and rictional agent.

t a sewing-needle be placed on the table of the universal arger, so that several charges of the electrical battery may nt through it in quick succession. This can be most con- ntly done by connecting Lane's discharger with the instru- . After the needle has been thus operated on, it will be d to possess magnetic properties, and the effect will be ased if the needle be placed in the magnetic meridian g the experiment.


Fig. 40.

e decomposing power of statical electricity may own by passing a succession of electric sparks from nachine through litmus or turmeric paper mois- l with a solution of sulphate of soda. The salt is decomposed by the electric agency; and the acid ated from the soda will colour the paper red if litmus ed, or if turmeric paper be the re-agent, the alkali ated from the acid will give it a brown stain. experiment succeeds better when the electricity ected from the prime conductor to the paper by ts, or by some other form of discharge which will a constant current of electricity of a lower e of intensity to act on the salt to be decomposed. e decomposition of water may be illustrated by ng a rapid succession of charges from a Leyden etween the ends of two wires inserted in a glass containing water, the ends of the two wires in water being about half an inch apart. At each discharge l bubbles of hydrogen and oxygen gases rise from the ends e wires in the proportion of two parts of hydrogen to

of oxygen, that being the proportion in which the two gases combine in the constitution of water. In the arrangement represented in fig. 40, there is a stop-cock at the bottom of the tube for the escape of the water, as the space in the upper part of the tube becomes occupied by the gas. The gases thus evolved, if mingled together, will explode when a light is brought near; and if the experiment be conducted with great care, and on a sufficiently large scale, a quantity of water will be formed by the re-union of the gases during the explosion, exactly corresponding in weight to that of the water decomposed.

CHAPTER VI.

ATMOSPHERIC ELECTRICITY.

a's observations of a thunder-storm—Mr. Crosse's apparatus and experiments r. Thompson's experiments with a lightning-conductor—Remarkable phenoa of a thunder-storm—Different conditions of artificial electricity and lightning ightning-conductors—Supposed danger from lateral discharge—Various ls of lightning-conductors—Safest place in a thunder-storm—Causes of the trical state of the clouds—Sheet lightning and forked lightning—Thunder— aurora borealis.

identity of lightning and electricity was fully proved by klin, and by the French electricians who succeeded, by imenting according to his directions, in drawing lightning the clouds. The fact was so completely established by the xperiments on the subject as to leave no doubt that lightis the effect of electrical discharge between the earth and louds. The principal object of succeeding investigations een to determine the peculiar conditions of the electricity e clouds, the means by which they become charged, the of the disruptive discharge, and the most effectual means of ling against its effects.

nor Beccaria, of Turin, a contemporary of Franklin's, made eful and very extended series of observations on lightning tmospheric electricity, which have scarcely been surpassed ose of succeeding electricians. In his experiments he made f kites and of pointed rods, and used a great variety of at different places. He paid particular attention to the rances presented by the clouds during thunder-storms, of h the following were the most remarkable:—

The first appearance of a thunder-storm is one or more e clouds increasing very fast in size, and rising into the er regions of the atmosphere. The lower surface is black nearly level, but the upper finely arched and well defined. y of these clouds seem often piled one upon another, all ed in the same manner, but they keep continually uniting, ling, and extending their arches. At the time of the foron, or approach of the dense cloud, the atmosphere is rally full of a great number of separate clouds, motionless, *of peculiar shapes.* All these, on the appear

thunder-cloud, draw near towards it and become more uniform in their shapes as they approach, until they coalesce into one uniform mass. When the thunder-cloud has increased to a great size, its lower surface is often ragged, particular parts being detached towards the earth, but still connected with the rest. Sometimes the lower surface swells into various large protuberances, bending uniformly towards the earth; and sometimes one entire side of the cloud will have an inclination to the earth, and the extremity will nearly touch the ground. When the eye is under the thunder-cloud, after it has grown large and well-formed, it is seen to sink lower, and darken prodigiously; at the same time that a number of small clouds are seen in rapid motion driving about in very uncertain directions under it. Whilst these clouds are agitated with the most rapid motions the rain generally falls in the greatest plenty, and if the agitation be exceedingly great, it generally hails.

"While the thunder-cloud is swelling and extending in branches over a large tract of country, the lightning is seen to dart from one part of it to another, and often to illuminate the whole mass. When the cloud has acquired sufficient extent, the lightning strikes between the cloud and the earth in two opposite places, the path of the lightning lying through the whole body of the cloud and its branches. The longer this lightning continues, the rarer does the cloud become, until at length it breaks in different places and shows a clear sky. When the thunder-cloud is dispersed, those parts which occupy the upper regions of the atmosphere are equally spread and very thin, and those underneath are black, but also thin; and they vanish gradually without being driven away by any wind, being dissolved into invisible vapour."

Experiments on a scale of vast magnitude were for some years conducted by Mr. Crosse, of Broomfield, near Taunton, a gentleman who, secluded within his own domain, which he converted into an extensive electrical laboratory, endeavoured to dive into the secrets of nature, and to trace the agency of electricity in the construction of rocks, and even in the creation of living creatures. This philosopher collected electricity from the atmosphere by means of what he termed an "exploring wire," which extended for several miles over his grounds. This wire was insulated, and connected with many pointed metal rods, which were supported and insulated on poles fixed to some of the highest trees in his park. These poles were erected in all directions, as far as the eye could reach, and the exploring wire connected with them was made to terminate outside the window of the laboratory. A thick wire communicating with the earth

was supported on a pole near to the exploring wire, to serve as a safety conduit for the electricity when it was emitted in such quantities as to become dangerous. When experiments were performed in the laboratory with the accumulated electricity collected by the exploring wire, it was introduced through the window by a connecting wire; convenient arrangements being made for applying the force with advantage, and for securing the safety of the operator.

The following is Mr. Crosse's account of the construction of a thunder-cloud, as examined by the exploring wire; and of his views of the distribution of the electricity:—

"On the approach of a thunder-cloud to the insulated atmospheric wire, the conductor attached to it gives corresponding signs of electrical action. In fine cloudy weather the atmospheric electricity is invariably positive, increasing in intensity at sunrise and sunset, and diminishing at midday and midnight, varying as the evaporation of the moisture in the air; but when the thunder-cloud (which appears to be formed by an unusually powerful evaporation, arising either from a scorching sun succeeding much wet, or *vice versa*) draws near, the pith balls suspended from the conductor open wide with either positive or negative electricity; and when the edge of the cloud is perpendicular to the exploring wire, a slow succession of discharges takes place between the brass ball of the conductor and one of equal size carefully connected with the nearest spot of moist ground. I usually connect a large jar with the conductor, which increases the force, and in some degree regulates the number of the explosions; and the two balls between which the discharges pass can be easily regulated, as to their distance from each other, by a screw. After a certain number of explosions, say of negative electricity, which at first may be nine or ten in a minute, a cessation occurs of some seconds or minutes, as the case may be, when about an equal number of explosions of positive electricity takes place, of similar force to the former, *indicating the passage of two oppositely and equally electrified zones of the cloud;* then follows a second zone of negative electricity, occasioning several more discharges in a minute than from either of the first pair of zones; which rate of increase appears to vary according to the size and power of the cloud. Then occurs another cessation, followed by an equally powerful series of discharges of positive electricity, indicating the passage of a second pair of zones: these in like manner are followed by others, fearfully increasing the rapidity of the discharges, when a *regular stream commences,* interrupted only by change into the opposite electricities. The *intensity of each new pair* of zones is greater than [illegible]

th ... the two balls to a greater
in
un ... vertical to the wire, the
gr ... lace, during which the
ba ... ursts of thunder without
re ... n accompanied by a crash
pr ... ving to get free between
th ... ect, which is not a little
ea ... the interchange of zones
th ... ved during this interval.
w ... My battery consists of
at ... t of surface on *one side*
m ... d, will perfectly fuse into
W ... in one length; such wire
th ... When this battery is con-
b ... ve, during a thunder-storm
... and of course as quickly
h ... oying my jars, I connect
di ... ry with brass balls one
th ... distances from each other
th ... ry receives three-fourths
o ... hunder-cloud is overhead.
w ... place between the balls.
li ... be conceived.
... opposite portions of the
... into play, and the effect
... l all dies away, and not
... here to affect a gold-leaf
... he air is remarkably free
... al, both before and after
... metimes, a little previous
... with the conductor will
... as if they were panting,
... urbance.
... an insulated plate, con-
... ductor, be electrified, the
... rom the centre to the
... squares of the distance
... cloud the reverse takes
... centre to the circum-
... rmed—say of positive
... e centre of the cloud,
... wer with the former;
... shing in power to the
... d, according to the

f inductive electricity, must exist, on the surface of the a nucleus of opposite or negative electricity, with its cor- ding zone of positive, and with other zones of electrified corresponding in number to those of the cloud above, gh each is oppositely electrified. A discharge of the e nucleus above into that of the negative nucleus below, nmonly that which occurs when a flash of lightning n, or from the positive below to that of the negative as the case may be; and this discharge may take place ing to the laws of electricity through any or all of the nding zones, *without influencing their respective electricities,* rise than by weakening their force by the removal of a of the electric fluid from the central nucleus above to elow; every successive flash from the cloud to the earth, n the earth to the cloud, weakening the charge of the of air, of which the cloud and the earth form the two te coatings."*

ould appear, therefore, from Mr. Crosse's observations of enomena of a thunder-storm, that the cloud from which ges occur is electrified in concentric rings, each one ng less intensely charged towards the extremity. As ng or zone must of course become enlarged as its distance he centre increases, the quantity of electricity in each zone obably be assumed to be equal; though to this point Mr. s observations do not extend.

ugh the electricity of the atmosphere is in all essential lars the same as the electricity excited by the machine, ndition in which it exists in a thunder-cloud is different ny that can be artificially produced, in consequence of the ude of the scale on which Nature operates. The strongest emitted from the most powerful electrical machine does eed two or three feet in length; and when numbers of parks are accumulated in an electrical battery, so as to , in a feeble manner, the destructive effects of lightning, rge, when spread over the surface of the glass, will not s way through more than two inches of resisting air. A ge between the clouds and the earth will sometimes occur he thunder-cloud cannot be less than 300 feet above the struck by lightning; though the resistance of the inter- e space is no doubt greatly diminished by the moist here and by rain. The electricity in the clouds immedi- efore the discharge must consequently be of a very high of intensity; and there is ample evidence, in the destruc-

* *Dr. Noad's Lectures on Electricity.*

tion of imperfectly conducting bodies, of the immense quantity of electricity concentrated in a flash of lightning.

The lightning-conductors attached to the tall chimneys of steam engines afford the means of making experiments with atmospheric electricity on a large scale. Mr. Lewis Thompson experimented in this manner with extraordinary results at one of the tall chimneys near Newcastle. The lightning-conductor was divided and separated a few inches near the ground, and in the passing of thunder-clouds, torrents of electricity, accompanied by a roaring noise, flashed across the separating space. In some of his experiments sparks fourteen inches long passed between the ends of the divided rod. He endeavoured to apply the electricity thus collected to the deposition of metals from their solutions, but without effect; for he could not succeed in coating a sixpence with the slightest film of copper. The decomposing power of the electricity was, however, very great when directed to the decomposition of water. For this purpose he distributed the discharge through several hundreds of capillary wires inserted in glass tubes, and obtained a copious evolution of gas. The hydrogen and oxygen were evolved together, instead of being exhibited separately, as is the case in ordinary decomposition by the voltaic battery.

A long spark from a powerful electrical machine, severed and *zig-zagged* by the resistance of the air, nearly resembles in form a flash of forked lightning; and in speculating on the mode of the action of lightning, the spark of an electrical machine, in consequence of its greater intensity, may be taken as bearing a closer analogy to it than the disruptive discharge of an electrical battery. In considering, therefore, the disputed question of the best mode of protection from lightning, and the effects of lateral discharge, we are more likely to arrive at safe conclusions if the character of the discharge from the prime conductor be examined, rather than the more powerful, though less concentrated, discharge of the battery.

The question in dispute in reference to the lateral discharge is, whether a lightning-conductor, allowed to be of proper thickness, will conduct a disruptive discharge safely from the clouds without danger of injury from the passage of the electricity in other than the direct course. It is adduced, as an illustration that there is danger in lightning-conductors, that when a discharge from an electrical machine is conducted to the earth by a very efficient wire, sparks may nevertheless be drawn from the wire at any part of its course, though sparks cannot be drawn when the conducting body applied to the wire is connected with *the wire itself.* It has hence been inferred, that to render a

lightning-conductor perfectly safe, all conducting bodies near it should have a metallic connection with the rod. The simplest mode of viewing the subject of lateral discharge, is to regard every discharge of lightning as distributed among *all* conducting bodies in the vicinity, and forcing its way through every course open to it in quantities proportioned to the facilities offered for its passage. According to this view, we must consider that in every flash of lightning there is not only a lateral discharge, but what may be termed a *distributive discharge* within a definite range.

The quantity of electricity that finds its way to the earth through these multifarious channels will be proportionate to their relative conducting powers. Suppose, for example, that a wire were joined to the lightning-conductor, and continued uninterruptedly to the earth; as much of the electric fluid would be conducted through that wire, in proportion to its thickness, as through the main conductor. If, however, the continuity of the wire were interrupted, the resistance occasioned by the imperfect connection would very materially diminish the quantity of electricity transmitted in that direction, though some portion would still pass through the divided wire. We may conceive that, in the same manner, every other substance, however imperfectly it conducts, transmits some portion, though it may be inappreciably small, of the infinitely divided charge.

The preceding consideration of the question is not calculated to diminish the value of lightning-conductors; but it points out the danger of dividing the discharge of lightning in such a manner as to direct a large portion of the electric fluid from its direct course. It was stated by Dr. Faraday, in evidence before the committee of the House of Commons, that a man would be safe even though leaning against the conductor of a ship when struck by lightning; nor is it probable that an appreciable quantity of electricity would pass from the continuous metal rod to find a devious and resisting course elsewhere; but if the man leaning against the conductor were at the same time to be standing on the iron cable, so as to form part of a communication with the sea by another course, there can be little doubt he would receive a shock more or less severe. The author's personal experience, as previously mentioned, enables him to speak of the distributive character of the discharge of lightning. When the electric fluid passed through his arm, that limb was sharing the discharge with many other and much better conductors of electricity; and though the sensible effect extended only from the wrist to the elbow, a smaller quantity of electricity must, *according to the principle of* distributive discharge, have passed

through his body to the support on which he was standing. A serious instance of distributive discharge of lightning occurred a few summers ago at Paddington. A row of buildings was struck by lightning, and four men, at work *in different houses*, were killed.

There has lately been much variety introduced in the forms of lightning-conductors. In the early days of their application, electricians questioned whether the elevated portion of the rod should terminate with a metal knob or a point, or whether it should be formed of a non-conducting substance. The point, however, gained the day, as it was rightly considered better to attract the electricity silently and gradually than to trust to the rod only for conducting a disruptive discharge. The notion of tipping the end with a non-conductor was simply absurd. Those who thus attempted to keep off lightning might with equal reason have erected a glass rod instead of a metal one. The opposite principle is now so generally adopted, that, with a view to increase the silent attraction of atmospheric electricity to lightning-conductors, it is customary to add several branching points. It may be questioned, however, whether any advantage is gained by more than a single point.

A recent invention, to which her Majesty's letters patent were granted, exhibits a curious misconception of the true properties of lightning-conductors. The patentee terminates his lightning-conductors with a great number of *magnetized steel points*, conceiving, no doubt, that as there is an intimate connection between electricity and magnetism, the magnetism of the points would add greatly to their attractive power. As iron and steel do not conduct electricity so readily as copper, the latter metal is the best for the purpose; and it is employed by Sir W. Snow Harris in his system of protecting ships from lightning. The greater expense of copper prevents its application to buildings, and a proportionally thicker rod of iron, coated with zinc, or, as it is commonly called, "galvanized," to prevent it from rusting, answers the purpose very efficiently.

At the meeting of the British Association for the Advancement of Science at Liverpool, a discussion took place in the presence of Professor Faraday respecting the best form of lightning-conductors for tall chimneys, lighthouses, and other high buildings. It was stated, that factory chimneys are frequently damaged by lightning in consequence of the metallic fixings of the conductor to the brick work, and to remove this source of damage it was proposed by Mr. Nasmyth, the inventor of the steam hammer, to suspend the conducting-rod inside the chimney by branching arms resting on the top. Several instances of damage caused by metallic

connections to stone work in lighthouses were mentioned by Professor Faraday, who strongly recommended that in all cases where lead or other metal is used to bind stone work together a metallic connection should be continued to the lightning-conductor.

Buildings having lightning-conductors elevated several feet above the highest point, are in little danger during a thunder-storm. In dwelling-houses not so protected, the place of greatest safety is an under-ground cellar. Those who are alarmed, and yet do not like to descend into the cellar, will do well to lie down on a sofa near the middle of the room, taking care to avoid the proximity of suspended metal chandeliers, or any other interrupted metallic body. Persons who are exposed out of doors in a thunder-storm should avoid taking shelter under trees; for though trees possess sufficient conducting power to attract lightning, they are not such good conductors as the fluids of the human body, and the electricity will consequently take its course to the earth through the better conductor.

In the mountain valleys of Savoy, application has been made of pointed rods to draw the electricity silently from the atmosphere for the purpose of protecting the vineyards from the destructive effects of hail, which frequently accompanies a thunder-storm. These conductors of electricity, termed *paragreles*, have been found to answer very effectively.

There is much variance of opinion respecting the requisite thickness of lightning-conductors. A French commission appointed to determine the question reported that a rod of iron seven-tenths of an inch square is quite sufficient under all circumstances. In the lighthouses and public buildings in this country, bars of copper three-quarters of an inch wide, and about a quarter of an inch thick are employed, and as copper conducts electricity seven times better than iron, these conductors are consequently much more efficient than those recommended for adoption in France; yet several lighthouses so protected have been damaged during thunder-storms. As the resistance of a metal rod to the conduction of electricity is greatly increased by its length, a thinner conductor is sufficient for a dwelling-house than is required for a lofty building.

Wires will sometimes serve to conduct lightning safely even when so thin as to be melted by its transmission. A remarkable instance of this kind is noticed in the following hitherto unpublished letter of Franklin's, which will be read with considerable interest:—*

* *The author is indebted to the kindness of* Charles Reed, Esq., F.S.A. [illegible] *letter, from his collection of manuscripts.*

"PHILADELPHIA, *March* 1, 1755.

"SIR,—I am but just returned from a long journey, after near six months' absence, and find your favour of September 29, by which I have the agreeable advice that you expect to be able to remit me something in Smith's affairs very soon.

"As to the thickness of wire necessary or sufficient to conduct a large quantity of lightning, concerning which you desire my sentiments, you will find something on that head in pages 124 and 125 of the enclosed pamphlet, which please to accept. And I may add, that in my late journey I saw an instance of a very great quantity of lightning conducted by a wire no bigger than a common knitting-needle.

"It was at Newbury, in New England, where the spire of the church steeple, being seventy feet in height above the belfry, was split all to pieces and thrown about the street in fragments. From the bell down to the clock, placed in the steeple twenty feet below the bell, there was the small wire above mentioned, which communicated the motion of the clock to the hammer, striking the hour on the bell.

"As far as the wire extended no part of the steeple was hurt by lightning, nor below the clock as far as the pendulum-rod reached, but from the end of the rod downwards, the lightning rent the steeple surprisingly. The pendulum-rod was about the thickness of a small tobacco-pipe stem, and conducted the whole without damage to its own substance, except that the end where the lightning was accumulated it appeared melted, as much as made a small drop. But the clock-wire was blown all to smoke, and smutted the wall by which it passed in a broad small black track, and also the ceiling under which it was carried horizontally. No more of it was left than about an inch and half next the tail of the hammer, and as much joining to the clock.

"Yet this is observable, that though it was so small as not to be sufficient to conduct the quantity with safety to its own substance, yet it did conduct it so as to secure all that part of the building. Excuse this scrawl, which I have not time to copy fair.—I am, with much respect, Sir, your very humble servant,
B. FRANKLIN.

"*P. S.*—I have just been reading a similar instance taken from the *Journal des Savans* for 1676, page 113, viz. :—

"'En 1676, le tonnere écrasa le clocher de l'abbaye de Saint Medard de Soissons; la foudre se porta à une grand distance le *long des fils* d'archal qui communiquoient à l'horloge; elle fondit

ces cordes métalliques sans faire d'autres désordres dans tout le trajet.'

"To Mr. JAMES BIRKIT, Merchant, Antigua,
Per Capt. SNOOK, J. D. C."

The continuous discharges of the electric fluid during a thunder-storm occur more frequently from cloud to cloud than between the clouds and the earth. These discharges of what are called "sheet-lightning" may often be observed at intervals of only a few seconds apart, and occurring with that rapidity for some hours, varied from time to time by discharges between the clouds and the earth.

Several causes have been assigned for the electrical condition of the clouds. The simplest hypothesis appears to be that founded on the *plus* and *minus* theory of Franklin, which well explains the varying circumstances of the accumulations of electricity in the atmosphere, and of its frequent changes from positive to negative. The fact that the natural capacity of a body for electricity varies with changes in the extent of its surface, has been already noticed. The capacity of steam and vapour for electricity, therefore, very greatly exceeds that of the water from which the steam is evaporated. Thus, when evaporation takes place from the earth, the vapour is combined with a vast quantity of electricity in a latent state. The condensation of the vapour into clouds diminishes its capacity, and a quantity of electricity is consequently set free, surrounding the particles of mist. As the mist collects into drops, a further amount of electricity is liberated, and the intensity of its condition is increased, though the actual quantity of electric fluid remains the same. On the other hand, when a cloud "melts into air," the capacity of the invisible vapour is greatly enlarged, and it absorbs the free electricity which was previously contained in the cloud. The changes continually taking place in the electrical condition of the clouds may thus be accounted for by the continual changes of state in the condensed vapour.

That the conversion of water into steam excites electricity during the enlargement of its volume, may be readily proved by the experiment of putting a hot cinder into water contained in a metal cup placed on the top of an electrometer. The sudden generation of steam immediately causes the gold leaves of the electrometer to diverge. The water, by increasing in volume, has its capacity for electricity increased, and absorbs it from all surrounding bodies, leaving the electrometer in a negative state.

During evaporation from the surface of the earth, th

trical condition of the vapour may be modified considerably by the comparative rapidity or slowness of the process; but it may be assumed that under all circumstances the vapour obtains, at the time of its formation, the quantity of electricity natural to its state of density; and that it does not become actively electrical, by being *plus* or *minus*, until it undergoes a change of state when it has risen in the air and become insulated from the earth.

When the clouds are in such a highly electrical state as to cause a discharge between them and the earth through a large intervening space of the resisting air, it might be imagined that one such discharge would neutralize the condition of the clouds, and that the thunder-storm would be ended. But it must be borne in mind that the condensed vapour of the clouds is a very imperfect conductor of electricity, and that one cloud, or a portion of a cloud, may have its electricity discharged, whilst another adjoining cloud remains fully charged; in the same manner that an excited rod of glass emits a succession of discharges to a conducting body brought to different points of its surface. Thus when the electricity of one cloud is discharged whilst the surrounding clouds remain in a highly electrical state, a constant effort is made to restore the equilibrium, and the discharges from cloud to cloud, called sheet-lightning, are the consequence.

The reverberating sound of thunder is produced by the devious course of lightning through the resisting air. The amount of such resistance cannot well be calculated, but as the resistance of the air to the motion of a musket-ball, when propelled at the rate of 1,600 feet in a second, is equal to twenty pounds on the square inch, or to 120 times the weight of the ball, some notion may be formed of the immense resistance encountered by the electric fluid in its instantaneous passage through the air. The first peal of thunder heard arises from the concussion of the air at the nearest point; therefore, assuming the direction of a flash of lightning to be from the clouds to the earth, the thunder will be first heard from the part where the lightning strikes the ground. The subsequent successive reverberations are occasioned by the comparatively slow progress of sound; those rumblings of thunder last heard being, in fact, caused by the first impulsive action of lightning on the air.

We have heard it remarked by Faraday as a curious error of artists in their representations of thunder-storms, that they make the lightning *pointed* towards the earth. Now, if it were possible to trace the course of a flash of lightning by the eye, *the part near* the clouds, being the more distant, would appear

to be much more pointed than that part which would be seen approaching the earth.

The phenomena of the aurora borealis and of "falling stars" are attributable directly to atmospheric electricity. In the upper regions of the atmosphere electricity is readily conducted, and flashes of electric light are transmitted through the highly rarefied air with little resistance. The experiment of sending flashes of light through an exhausted receiver exemplifies, with considerable accuracy, the phenomenon of the aurora, but there are other circumstances connected with it, in reference to the sources of electrical excitement and the conditions in which the electricity is developed, that remain undetermined.

CHAPTER VII.

ELECTRICITY FROM HIGH-PRESSURE STEAM.

Steam, an abundant source of electrical excitement—Friction of water the cause of excitement—Faraday's experiments on High-Pressure Steam—Hydro-Electrical Machine—State of the electricity excited by it—Combination of quantity and intensity—Effects of the Electricity thus excited on a large scale—Various conditions of the Electricity excited.

THE excitement of electricity by the emission of high-pressure steam is the most recently discovered means of disturbing the electrical equilibrium; and it affords a more abundant supply of electricity of great intensity than any other artificial source.

The circumstances that led to the discovery of steam-excited electricity have been already mentioned,* and we have also stated that this peculiar excitement of the force is due to the friction of particles of water issuing from the steam jet. It had, indeed, been long known that the friction of fluid particles, or of the minute particles of bodies not ordinarily considered as electrics, gave rise to electrical phenomena; but there seemed to be great difficulty in admitting that the friction of particles of water—the presence of which fluid in ordinary cases is the chief impediment to electrical excitement—should be a source of electricity.

Before considering these remarkable phenomena, we shall notice some of the previously known facts that have the closest analogy to them.

When the powder of almost any substance is introduced into a pair of bellows and blown against an inclined plate or a metal sieve, electricity is developed. Even when powdered ice or fine frosted snow is in this manner expelled through the nozzle of the bellows, there is a strong excitement of electricity. When metal filings slide along a plate of the same kind of metal, or are shaken through a wire gauze, the same effect is produced. It is observed in these and in all similar cases, that the metal against which the particles impinge is in an opposite state of electricity to the powder itself. Proceeding from the friction of powders to that of liquids: if paper, cotton, or other non-con-

* *History of Electricity*, page 50.

ducting bodies having a rough surface be quickly immersed in mercury, or if particles of mercury be allowed to fall upon them, signs of electricity are exhibited. Alcohol, varnish, or liquid resins projected against roughened glass, or against an insulated metal plate, also excite electricity.

In the foregoing phenomena the electricity is excited without any change of state in the substances exciting it, and we at once attribute the cause to friction. But in the case of electricity developed by the emission of high-pressure steam, there is a change of condition from a highly compressed to an expanded form, that seems sufficient to account for the excitement of the electricity without admitting the seeming anomaly that water is an electric. The experiments of Faraday, however, have placed the question almost beyond doubt.

The apparatus he employed in those investigations consisted of a cylindrical steam-boiler, which was insulated by being placed on three blocks of shellac, and had attached to it a horizontal tube about five inches long. Near the end of the tube was a large stop-cock and a hollow metal globe. In the circumference of this "steam globe," opposite to the tube, was an aperture into which he could screw the jets of various forms with which he operated. The diameters of the jets were small compared with the size of the globe and of the diameter of the

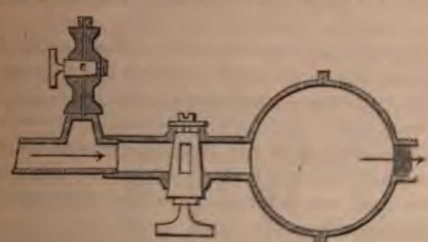


Fig. 41.

Fig. 43.

tube connected with the boiler. Fig. 41 represents the steam-tube and hollow globe; and figs. 42 and 43 show two of the jets attached to the globe for the emission of the steam. One of these, fig. 42, consisted of a metal tube shaped like a funnel, and a small cone attached by a screw to an insulating arm, so that the distance of the cone from the aperture of the small jet could be accurately regulated. The other jet, fig. 43, was supplie

Fig. 42.

a feeding channel joined to it, and furnished with a stop-cock, so that any liquid in the vertical pipe might be allowed to flow into the jet during the emission of the steam. All the experiments were made with steam not exceeding in pressure ten pounds on the square inch. The electricity of the boiler was indicated by an electroscope, or by a discharging electrometer, and it was the electricity of the boiler that was generally observed in these experiments.

To prove that the electricity excited by the emission of steam from the boiler is not attributable to mere change of state or vaporization, the valve was opened wide without allowing the escaping steam to impinge on any solid matter, and under those circumstances the boiler exhibited no sign of electricity. Neither was there any electrical indication when the steam was allowed to escape through the jet, fig. 42, without being combined with moisture. So soon, however, as water collected in the jet and was impelled by the issuing steam against the small cone, powerful electrical excitement was apparent. From this circumstance Faraday inferred that the electricity excited was due to the friction of the particles of water against the cone. To produce this effect, however, it is necessary that the water should be pure and unmixed with anything that improves its conducting power. The introduction of a drop of acid or a crystal of salt into the steam globe was sufficient to destroy the effect.

Cones of various kinds were tried to ascertain if the electrical excitement varied with the substance against which the friction of the water took place. It was found that with some substances—ivory more especially—there was scarcely any electricity developed. This variation in the degree of excitement is a further proof that the effect is due to friction. In all cases the electricity developed on the resisting cones was negative, and that of the steam positive.

By using the second apparatus, fig. 43, various kinds of fluids could be introduced into the jet, and thus the effect of their friction against the cone could be ascertained. Spirits of turpentine, oils, and varnishes, were introduced into the vertical tube, and allowed to fall through the stop-cock near to the orifice of the jet. In all these cases electricity was evolved, but its character was changed. The vapour thus charged with resinous particles became negative, and the boiler itself was charged positively.

Still further to prove that the electricity excited was caused by friction of the liquid particles, and not by changes of state in the steam, Faraday attached the jets to a globe of compressed

air. When moist air was thus allowed to impinge against the obstructing cone, there was a development of electricity; but when the air was perfectly dry no electricity was perceptible.

By means of the feeding tube, fig. 43, experiments could be readily made with various kinds of powders, such as sulphur, starch, rosin, powdered flint, &c. In these cases electricity was powerfully developed, and the character of the electricity was, as might have been anticipated, changed by the nature of the substance and of the cone against which the frictional action occurred.

The effect of the excitement of electricity by the emission of high-pressure steam is not fully developed unless the steam be raised to a pressure of fifty pounds on the square inch. The apparatus constructed for exhibition at the Polytechnic Institution is the largest machine of the kind yet made. The boiler A A, fig. 44, is constructed on the same principle as the tubular

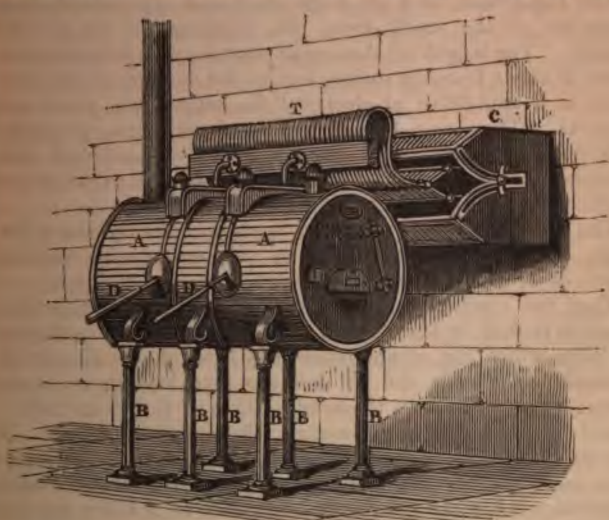


Fig. 44.

boilers of steam engines; being perforated longitudinally by tubes, through which the draught of the furnace passes. The length of the boiler is six feet six inches; its diameter, including the furnace, which is in the centre, is three feet six inches. There are forty-six bent tubes, T, at the top for the escape of the steam. *These tubes* are made of iron, but the jets through

which the steam issues are formed of partridge wood; that material having been found by experience to give the best results. In front of the jets there are several rows of metallic points, for the purpose of conducting the electricity, as quickly as it is excited, to the earth, and thus to prevent its return to the boiler from which the sparks are taken. The boiler is insulated from the ground by six stout glass pillars, B B B, about three feet high, on which the apparatus rests.

The pressure of steam commonly used in experimenting with this apparatus is sixty pounds on the square inch. When in full operation, with steam issuing from the forty-six jets, the torrents of electricity evolved bear some resemblance to those described by Mr. Crosse as having poured forth from his exploring wire during a thunder-storm. The electricity excited combines quantity with intensity. Though the sparks emitted are not so long as those from the large plate-electrical machine in the Institution, they are more dense, and approximate to the character of the spark from the discharge of an electrical battery. The length of the sparks that may be taken from the boiler is about fourteen inches, and at the distance of six inches there is a rapid flow of electrical discharges, too quick to be counted. The large battery of the Institution, comprising eighty-four feet of coated surface, is fully charged in eight seconds; though it requires at least fifty seconds to be charged by the plate-electrical machine in its best action.

The sparks from this apparatus ignite gunpowder and inflame paper and wood shavings, and by this means also numerous effects of electro-chemical decomposition can be exhibited.

That the excitement of electricity by effluent high-pressure steam is caused by the friction of condensed water against the jet from which the steam issues, has been shown also by this apparatus; for when the jet and the pipe leading to it were heated, so as to prevent the condensation of the steam before it issued forth, scarcely any electrical effects were produced. The amount of electricity was increased by lengthening the pipe, so as to cause greater condensation. It is for this object that the emission pipes of the apparatus are bent so as to allow the water to collect near the apertures.

With the small apparatus employed by Faraday in his experiments the effects were very feeble compared with those of the hydro-electrical machine at the Polytechnic Institution. In some respects, however, this more feeble excitation of electricity was of advantage, as it afforded the opportunity of detecting changes of state that would not probably have been noticed under the influence of much stronger pressure. It was found, for

instance, that electrical effects could only be obtained with those lower pressures when distilled water was employed. The addition of any soluble substance that improved the conducting power of the fluid, prevented its acting as an electric with so low a degree of friction.

One of the many curious results derived from these experiments is, that water may claim to rank among the first of positive electrics. Faraday, indeed, conjectures that further investigation will place it at the head of all substances as a positive electric; for even glass became negatively electrical when exposed to friction with the emitted steam of pure water.

The excitement of electricity by effluent steam affords a striking illustration of one of the numerous ways in which electrical agency operates without our consciousness of its presence. An ordinary locomotive engine generates, during every minute of its onward course, a force sufficient to destroy instantaneously all the passengers it propels. This force, however, is dissipated as soon as it is created, and it was only by accident that its existence became known. It is the same with nearly all the chemical changes that are taking place around us. Even the burning of a candle, there is reason to believe, puts in action an amount of electricity greater than that of a thunder-cloud, though no means have yet been discovered of eliminating the force by preventing it from being dissipated unperceived. In some other chemical actions, however, less energetic than combustion, the accompanying electricity can be not only detected, but it is developed in quantities, compared with which the excitement of it by friction is altogether insignificant. The consideration of the phenomena of the electricity excited by chemical agency, to which we are about to direct attention, constitutes, indeed, the most important practical branch of electric science.

CHAPTER VIII.

EXCITEMENT OF VOLTAIC ELECTRICITY.

[illegible] of electricity by metallic contact and by chemical action—Mu[illegible] [illegible] of chemical action and electricity—Simple Voltaic circle—Cons[illegible] of the Voltaic pile—Identity of Voltaic and frictional electricity—[illegible] *de tasses*—Conditions requisite for the excitement of Voltai[illegible] [illegible]—Solid and Liquid elements of the battery—Their actions and re-a[illegible] Faraday's hypothesis of conduction through fluids—Resistance to the current—Ohm's formula—Local action in batteries.

THE discovery, by Galvani, that muscular contractions a[illegible]
[illegible] by the contact of dissimilar metals, and the rapid [illegible]
[illegible] additions to that discovery by Volta and others, hav[illegible]
noticed in our introductory sketch of the history of elec[illegible]
We shall now proceed to explain more particularly the
[illegible] and phenomena of the force thus generated by ch[illegible]
action.

The simplest manifestation of the excitement of a p[illegible]
force by the contact of metals is obtained by placing a p[illegible]
[illegible] under the tongue, and a piece of silver upon it, an[illegible]
[illegible] the metals to touch. Before contact, no sensa[illegible]
[illegible] beyond the mere pressure of the two hard sub[illegible]
[illegible] the tongue; but the instant that contact is mad[illegible]
[illegible] by a strong metallic taste, which continues w[illegible]
[illegible]. The same sensation will be perceived, if,
[illegible] are kept separated, a metallic connection be[illegible]
[illegible] by touching each one with another piece of
[illegible] of zinc is immersed in diluted sulphuri[illegible]
[illegible] immediately commences. The water is [illegible]
[illegible] superior affinity of its oxygen for the zin[illegible]
[illegible], and the hydrogen is liberated in a c[illegible]
[illegible]. The decomposition continues unt[illegible]
[illegible] exhausted by the combination of the s[illegible]
[illegible], in connection with the oxygen por[illegible]
[illegible] particles of water, soluble sulphate o[illegible]
[illegible] chemical action which takes place [illegible]
[illegible] gas for experimental purposes.
[illegible] gas evolved in these cases is exact[illegible]
[illegible] that combines with the zinc with
[illegible] in the water decomposed.

When the surface of the zinc plate is well amalgamated with mercury, the continuous decomposition of the water is prevented. Only those particles of fluid in immediate contact with the metal are then decomposed. The hydrogen gas collects in minute bubbles over the surface of the plate; but they do not attain sufficient size to detach themselves from the metal, and the plate consequently becomes coated with innumerable minute bubbles of hydrogen gas. This gaseous coating protects the metal from being further acted on by the acidulated water; and it would thus remain in the liquid, unchanged, for a length of time.

A piece of sheet copper may be immersed in the same vessel without causing any alteration in the state of things, so long as the metals are kept apart. Bring the copper gradually closer to the zinc, until scarcely any perceptible space intervenes, still there will be no change; but the instant that the metals touch, a brisk action commences. The bubbles on the surface of the zinc are transferred to the copper, and rise rapidly to the top of the fluid; these are followed by continuous successions of bubbles of gas, all rising from the copper surface, as if the chemical action were taking place with that metal. It is the zinc, however, that is alone attacked, and being deprived of its protecting coating of bubbles, it continues to be converted into sulphate of zinc, until, as in the previous case, the free sulphuric acid is exhausted.

It is not necessary for the production of this effect that the metals should touch in the fluid. If the lower parts only of the plates be immersed, and the upper ends are brought together, the formation of bubbles proceeds quite as briskly as when the metals are in contact in the liquid. Neither is it requisite that the copper and zinc plates should touch each other. If the lower ends be immersed, and the parts out of the fluid be connected with a wire, as in the annexed diagram, the evolution of bubbles from the copper surface will continue, though not so rapidly as before. The diminution in the action arises from the resistance which the wire offers to the passage of the stimulating force, but by increasing the thickness of [the con]necting metal, the evolution of gas becomes more bri[sk]

Fig. 45.

...nt shown in the figure, let ... the extent of surface im... ...re inches. The total evolu... will be greater than before, ...sed extent; for if the thick... ...o not correspond with the ...ill diminish the effect. Let ...nother remarkable phenome... ...s then so much greater than ...: that thin wire, that it is ...e wire will become red hot. ...e even melted in the act of ... peculiar power by means of

...ction bear but little apparent ... power of decomposing water ... common to both; but it is ... that no argument in favour of ... founded on those phenomena ... is the means of assimilating ...ity to that of the electricity

... and copper plates in a vessel ...e of cloth soaked in the same ...etals, the effect will be nearly ...ontained in the cloth acts on ...metallic connection is made ... similar results may be thus ...shed in effect.

...ady means of increasing the ...on of a single pair, of which ...ructed a pile consisting of a ... moistened cloth interposed ...th a zinc disc. Upon that ...e; on that a circular piece ...al discs, having previously ...ed. On the cloth was laid ... again cloth, and so on in ... of alternate metal discs and ...sented in fig. 46. To pre... ...ere supported by vertical ... ...ced on the top to keep

... the plates in such an ...s previously moistened,

decided shock is perceived, exactly resembling that from den jar feebly charged. The shock differs, however, from f a Leyden jar in the continuity of ect, for similar shocks are continued id succession as long as the con- n between the plates, through the is maintained. This physiological presents a clear analogy to the of the Leyden jar; and different he manner of its excitement, and nt also as are many of the mani- ons of the chemical agent, the ulation of the force in the Voltaic ointed out at once its identity electricity. Subsequent investi- s, more especially the experimen- searches of Faraday, have estab- this identity in almost every ular.

Fig. 46.

action of the Voltaic pile gradually diminishes from the t is first put together, until at length the effect appears to This diminution of power is more rapid in proportion to ergy given to the pile in the first instance by the larger ity of acid mixed with the water. To restore the original , it is necessary to decompose the pile, to clean the zinc opper discs, and to moisten the cloths again. Such an atus is therefore attended with much trouble. To obviate olta contrived another arrangement, which he called *à ne de tasses.* He connected a piece of zinc to a piece of r by soldering to them a short length of bent copper wire. g procured a number of plates so connected, he put them lasses placed in a circle, and containing acidulated water, care so to dispose them that the zinc and the copper con- l together should be in separate glasses, in the manner ented in fig. 47.

the copper plate in glass 1, a wire is attached to serve as luctor for forming connection. In the same glass there is plate connected with the copper immersed in glass 2. In nanner each glass contains a zinc and copper plate con- l by a wire. The plates are kept apart in the fluid, and eries may be continued to any extent. By bringing the attached to the first plate in connection with a similar oldered to the zinc plate in the last glass of the series, the immediately commences, and it is more or less intense

... plates. This arrangement is, in ... to the pile. A much larger quan... to act on each plate, consequently ... diminish; the plates can be readily

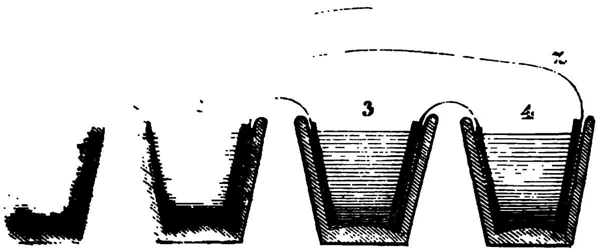


Fig. 47.

...ratus is not wanted, and the acidulated ... for the immersion of the plates when ...

... *couronne de tasses* as invented by Volta ... modifications for convenience in use, to ... that is most generally employed. A ... consisting of 100 plates of copper and zinc ... generate electricity in sufficient quantity ... manner most of the phenomena of ... is desirable, however, before noticing ... phenomena of the voltaic battery, that we ... of its action.

...gement of a single pair of plates (fig. ... conditions necessary for the excitement ... action. We observe two metals ... a much stronger affinity to oxygen ... similarity in the chemical affinities of ... in all similar arrangements to be ... excitement of electricity; and the ... great or small according to the degree ... their relations to oxygen.

... electricity by their mutual actions are ...; those placed first acting in ... copper does to zinc:—

...	7. Tin.
...	8. Iron.
...	9. Zinc.

... will constitute what is termed

a voltaic circuit. Thus, zinc will excite voltaic action in combination with iron; iron will take the place of zinc when combined with tin; and tin will take the place of iron when combined with copper. The energies of these combinations increase as the metals are more distant from each other in the scale. Thus the most powerful practical combination is that of zinc and platinum; the former being the most corrodible, and the latter the least corrodible of the ordinary metals.

Though two plates are necessary in such an arrangement, only one of them is active in the excitement of electricity, the other plate serving merely as a conductor to collect the force generated. A metal plate is generally used for that purpose, because metals conduct electricity much better than other substances which expose an equal surface to the fluids in which they are immersed; but other conductors may be used, and when a proportionately larger surface is exposed to compensate for inferior conducting power, they answer as well, and in some instances even better than metal plates. Charcoal has been employed as one of the elements of a voltaic battery; but the most advantageous is graphite, a very hard substance that is found encrusted within gas retorts. As it is altogether impervious to the action of acids, it may be ranked even above platinum in the scale of non-oxidizable bodies; and though not so good a conductor as that metal, its finely granulated or crystallized texture exposes so large a surface to the fluid, that the conducting power is practically nearly equal to it.

We have hitherto considered only the solid elements of the voltaic battery. They form, indeed, the most conspicuous parts of the arrangement, but they serve merely as the intermediate agents for the development of the electric force. The chemical action that gives rise to the excitement of electricity takes place during the decomposition of the liquid in which the plates are immersed. It is essential, therefore, to the formation of an active voltaic arrangement, that the liquid employed should be capable of being decomposed. Water is most conveniently applicable for the purpose. Its elements, oxygen and hydrogen, are separated by the superior affinity of the oxygen for the zinc; especially when that affinity is heightened by the connection of the zinc with an incorrodible metal, to which the hydrogen gas of the decomposed molecules of water is attracted. Whether the electricity evolved be the cause or merely the effect of chemical action, is at present unknown. In whichever way the phenomenon be regarded, the electricity appears to be excited at the surface of the active plate, to be thence transferred to the conducting plate, and back again through the

... the zinc, forming what is termed an electric ...

... very imperfect conductor, it offers so much ... the passage of the electric current that a very ... of voltaic electricity can be excited when water ... employed; especially when the plates are at a considerable ... apart. By the addition to the water of an acid or ... salt, the conducting power is greatly increased, and ... current is augmented in a corresponding degree. It is ... point whether the increased action from the addition ... arises from the improved conducting power alone, or ... is to be attributed also to the increased affinity of ... of the acid to the zinc. The effect is most probably ... the joint effort of the two forces.

... essential to the excitement of voltaic electricity that ... metals should be employed. A voltaic circuit may be ... by a single plate of metal, provided its two surfaces be ... differently, and the exciting liquids be kept apart. ... the plate be cemented into a trough so as to divide ... into two water-tight compartments, and diluted ... acid be poured into one compartment, and a solution ... salt into the other, there will be a strong manifestation ... electricity on making metallic connection between the ... Nor is it necessary that different exciting liquids ... employed, for if one of the surfaces of the zinc plate ... and the other rough, so as to produce different ... action on the two surfaces, a similar effect will be ...

... opinion of Faraday, the conduction of electricity ... liquids is accompanied by, if it be not owing to, the ... decomposition of the intervening particles. When a ... the plate, for example, are connected together and ... diluted acid, the oxygen in the particle of liquid

... fluid" and "electric current," which are frequently ... phenomena, are calculated to mislead the student ... electricity is known to be a fluid, and that it flows in a ... Such terms, it should be understood, are founded ... of the electric force to fluid bodies. The nature of ... whether its transmission be in the form of a current, or ... means, is undetermined. At the meeting of the ... Advancement of Science at Swansea, a discussion arose ... Dr. Faraday was called on to give his opinion. He ... when I thought I knew something about the matter; ... carefully I study the subject, the more convinced ... nature of electricity." After such an avowal from ... the age, it is almost useless to say that any terms ... nature of electricity are merely to be considered as ...

contiguous to the zinc enters into combination with the metal, and its equivalent quantity of hydrogen is disengaged. The hydrogen is not immediately liberated, but is transferred from particle to particle of the liquid in a continuous chain till it reaches the conducting plate, where, not meeting with any more liquid particles to which it can be transferred, it is liberated in the gaseous form. The intervening particles are supposed to undergo temporary decomposition during this transfer from plate to plate, and to assume a polar condition, the oxygen and hydrogen occupying opposing places in each particle of liquid.

The annexed diagram (fig. 48) shows, in an exaggerated form, the chain of particles of water through which the decomposing influence is supposed to be transmitted. Voltaic action having been established through water in the vessel A from the zinc plate Z to the copper plate C, the particles between the two metals are thrown into a polar state; the oxygen of each being directed towards Z, and the hydrogen towards C. The zinc plate absorbs the oxygen of the particle nearest to it, and the liberated hydrogen combines with the oxygen of the next

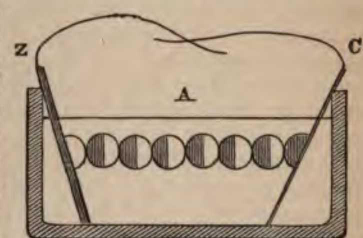


Fig. 48.

adjoining particle, and in this manner a continuous interchange takes place. According to this view of the conducting power of fluids, no fluid can conduct electricity unless it be capable of being decomposed; the conduction being necessarily accompanied by a train of successively decomposed particles.

All chemical action is believed to be accompanied by the development of electricity, though in only a very limited number of arrangements can it be observed. It is necessary for the sensible development of the force that the elements of bodies undergoing decomposition should be separated from each other in an imperfectly conducting medium, and be transferred in different directions. These conditions are complied with in a voltaic arrangement of a pair of plates of dissimilar metals, immersed in a decomposable fluid. The positive and negative electricities thus developed, which in ordinary chemical combinations immediately coalesce imperceptibly, are in the voltaic battery constrained to separate, and in order to reunite must pass along the conducting substances that connect the generating and the conducting plates. But even the best voltaic arrange-

ments do not develop the whole of the electric force accompanying chemical decomposition.

The causes that obstruct the development of electricity in a current have been minutely investigated by Professor Ohm, of Nuremburg, who has reduced them to mathematical formulæ. The free development of electricity is opposed, in the first place, by the affinity of the elements of the exciting liquid for each other, tending to resist decomposition; secondly, by the imperfect conduction of the fluid itself; and in the third place, by the resistance of the conducting-wires. As the formulæ deduced by Professor Ohm from these investigations have received general acceptance among electricians, it is desirable to put them on record, and we cannot do this in a better manner than by copying the lucid explanation of them by Dr. Golding Bird.*

"E = electro-motive force, equivalent to the affinity of the exciting liquid for the generating metal, and corresponding to the amount of electricity which would appear in current if all opposing causes were removed.

"R = resistance opposed to E by the contents of the cell, arising for the most part from the affinity of the elements of the exciting liquid for each other.

"r = external resistance, arising chiefly from the imperfectly conducting nature of the wires used to convey the current.

"a = active force, or the amount of electricity which really reaches the end of the conducting-wire.

$$a = \frac{E}{R+r}$$

"The theoretical value of E is diminished materially in practice by the affinity of the conducting-plate for the ingredient of the exciting fluid, which tends to combine with the generating plate; this affinity, however weak, is still seldom absolutely null. The mutual affinity of the separated elements of the fluid evolved at the surfaces of the plates also lessens the intensity of E.

"The internal resistance, R, varies directly with the distance, D, between the two plates, and is inversely as the area of the section, S, of the exciting liquid. Thus, the real resistance is equal to the former divided by the latter, or

$$R = \frac{D}{S}$$

"r, or the external resistance, so far as it is dependent on

* *Elements of Natural Philosophy.*

the conducting-wire, varies *inversely* as the square of the diameter of the wire, s, and directly as its length l, or

$$r = \frac{l}{S}."$$

From these formulæ are deduced the following general laws:—

1st. The electro-motive force of a voltaic circuit varies with the number of the elements, and with the nature of the metals and liquids which constitute each element; but it is in no degree dependent on the dimensions of any of their parts.

2d. The resistance of each element is directly proportional to the distances of the plates from each other in the liquid, and to the specific resistance of the liquid; and it is also inversely proportional to the surface of the plates in contact with the liquids.

3d. The resistance of the connecting wire of the circuit is directly proportional to its length, and to its specific resistance, and inversely proportional to its section.

It must be remarked that the foregoing estimate of electrical force and resistances does not take into account the actual loss of electricity by the want of proper direction. The chemical action that converts any given quantity of zinc into a metallic salt develops a given quantity of electricity. Let it be assumed that one ounce of zinc will generate an amount of electricity equivalent to 1,000; that quantity will not be diminished by the resistances considered by Professor Ohm. Those resistances relate exclusively to the time in which a given amount of electricity can be generated, and have no relation to actual loss of electric force. Thus, in a well-constructed voltaic apparatus no more electricity is generated than can flow in a current through the conducting-wire. If the resistance to the current be increased by diminishing the thickness of the wire or by adding to its length, the action of the generating-plate is diminished in a corresponding degree, so that if only half the electricity is developed, only half the quantity of zinc is consumed; and to whatever extent the resistances are increased the ounce of zinc will, theoretically at least, produce its equivalent of electricity, though in a longer time.

In practice, however, an actual loss of electricity does generally occur, arising principally from what is called "local action" in the generating-plate. If a plate of zinc were perfectly pure and homogeneous, no chemical action would ensue when it was immersed in diluted acid. But zinc, as it is commonly procured, contains copper, iron, and other impu-

which serve to set up voltaic action over its whole surface when exposed to diluted acids, and that causes a rapid decomposition of the liquid. The positive and negative electricities thus generated immediately combine, and are neutralized imperceptibly, and much electric force is consequently absolutely lost. This local action is in a great measure, though not entirely, prevented by amalgamating the zinc plates with mercury. This is readily done by first dipping them in diluted sulphuric acid, and then sprinkling a few drops of mercury on the surface and rubbing them over with a cork. The effect of amalgamation is to produce a homogeneous surface, and to protect the zinc from the action of the diluted acid until the affinity of the liquid for the metal is increased by the agency of the conducting-plate.

CHAPTER IX.

VOLTAIC BATTERIES.

Intensity and quantity of electricity considered—Transference of accumulated action from plate to plate—Faraday's view of the action of the Voltaic Battery—Different constructions of Voltaic Batteries; Cruikshanks', Babington's, Wollaston's, Daniell's, Smee's, Grove's, Bunsen's, Callan's, gaseous—General principle of construction.

THE electricity generated by a single pair of plates possesses a very low degree of intensity. The *quantity* is only limited by the size of the plates, but no increase of size alone will add to the *intensity* of the force. Thus, though a pair of large zinc and copper plates, immersed in diluted sulphuric acid, will fuse any of the metals, the electricity they excite cannot decompose a drop of pure water, because the force is not sufficiently energetic to overcome the resistance of the fluid.

To increase the intensity of the force it is necessary to form a series of conducting and generating-plates on the principle of Volta's arrangement *à couronne de tasses.*

It will simplify the explanation of the mode of operation of this combination of plates, to consider, in the first place, the combined action of two pairs of plates only. In fig. 49, A and B are two cells, containing diluted sulphuric acid. Into cell A an amalgamated zinc plate z is immersed; it being connected by a wire to a copper plate c in the cell B. No voltaic action would ensue between those two plates, because, being in separate cells, the hydrogen element of the particles of water set free at the zinc plate could not be transferred to the copper. But by introducing a second pair of zinc and copper plates z' and c' into the cells, the transfer *could take* place, and the electric current would pass, *first from* z *to t*[illegible]r c', thence it would be conducted to

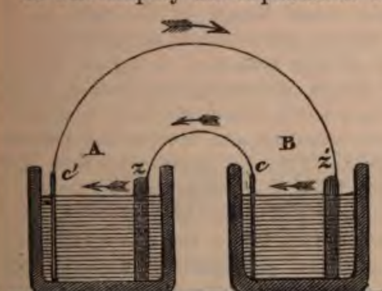


Fig. 49.

second zinc plate z' by the connecting wire, and from that through the fluid to c, and back again to the first generating-plate by the shorter wire, which completes the circuit.

In tracing the course of the electric current thus established, no notice has been taken of the action of the second zinc plate z'. If that be considered as inactive, except as a conductor, the quantity of electricity transmitted would be very small, owing to the resistance of the imperfectly conducting liquid. But the zinc plate in the second cell is acted on by the diluted acid equally with that in the first; and the effect is to nearly double the energy of the electric current excited by the action of the acid on the first zinc plate.

The cause of this increased action is easily intelligible on the supposition that the electricity excited by each zinc plate is added to that transferred to it from other plates in the series and carried forward to the next in succession. Thus, for instance, a certain quantity of electricity having been excited by the zinc plate in cell A, it is transferred to the conducting-plate c' in the same cell; and if a metallic connection were made between those two plates, the electricity would be directly returned in a short circuit to z. But as there is no metallic connection with the zinc, the electricity must pass through the wire to the surface of z', which acts as a conducting-plate. The action of the acid on the zinc in the second cell excites at the same time a quantity of electricity equal to that it receives from the first plate; and this accumulated quantity being compressed within the same space, is transmitted with redoubled energy through the fluid to the second conducting-plate c, and thence by the wire to the first generating-plate z, to restore the electrical equilibrium.

According to this view of the action of a voltaic battery consisting of two pairs of plates, the electricity excited by the first zinc is transferred to the second, where its force is doubled by the excitement of an equal quantity, and both united traverse the wire of the return circuit. On arriving at the first zinc, the quantity it excited, being half the accumulated amount, is parted with; but an equal quantity of fresh electricity is excited, and is carried on to the second zinc, where the same process is repeated; and thus the electrical equilibrium is continually disturbed and continually restored after traversing the wires that connect the plates at the extreme ends. When greater numbers of zinc and copper plates are united in a series, a similar transference of electricity from plate to plate takes place with a progressively increasing intensity of force, the action being continued as long as the series remains unbroken, or until the fluid becomes saturated with sulphate of zinc, and further chemical action is prevented.

It is necessary to state that the preceding explanation of the action of the voltaic battery differs from the view taken of it by Dr. Faraday, M. de la Rive, and other writers on the subject. In the opinion of Dr. Faraday, addition to the number of plates in a series occasions no addition to the *quantity* of electricity generated by the first pair of plates, but merely serves to give increased intensity to that quantity. Thus the most powerful effects produced by a voltaic battery consisting of 1,000 pairs of plates, are assumed to be caused by the same *quantity* of electricity that is excited by a single pair only of the series: the exalted action in the former case being attributed to an increase of intensity without any addition to quantity. This view of the nature of the action of the voltaic battery is supported by numerous ingeniously-contrived and apposite experiments;* but though fully disposed to pay the highest possible respect to so great an authority as Dr. Faraday, we think he has failed to establish the position that increased intensity is not accompanied by addition to quantity.

There are many arrangements of voltaic batteries for the development of accumulated electric force in different modes, but they all depend on the same principle. The most compact is Cruikshanks' modification of the voltaic pile. Zinc and copper plates of equal size are soldered together, and then cemented into a wooden trough. Each pair of plates is fixed less than half-an-inch from each other, care being taken that all the zinc and copper surfaces are turned the same way. The compartments between the plates form water-tight cells, into which diluted acid, or other exciting liquid is poured. A piece of wire is introduced at each end to complete the circuit through any substances to be subjected to the voltaic action.

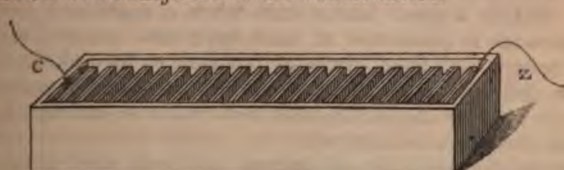


Fig. 50.

A series of fifty of these small double plates may be cemented into a trough two feet and a-half long; and two such batteries, with plates two inches square, will give a rapid succession of smart shocks, and will exhibit many of the phenomena of voltaic electricity. The disadvantages of a battery of this kind are,

* *Experimental Researches.*

that the exciting liquid cannot be emptied at the end of each experiment without much trouble, and there is some difficulty in cleaning the plates when they become corroded. By emptying the cells as soon as possible and washing them with water, a battery of this construction may, however, be kept in order for a considerable time; and when voltaic electricity of high intensity and small quantity is required, a Cruikshanks' battery, with plates about two inches square, is very convenient.

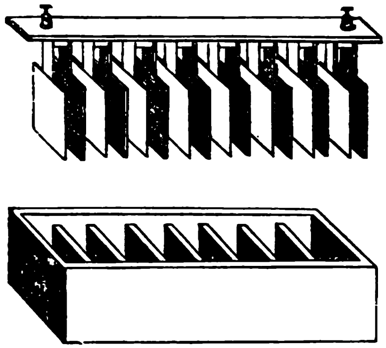


Fig. 51.

An arrangement contrived by Dr. Babington affords the advantage of making the plates easily accessible for the purpose of cleaning, and also of removing them from the liquid when the experiment is ended. An earthenware trough is divided by plates of the same material into water-tight compartments about two inches wide, so as to form a number of cells. Each pair of zinc and copper plates is connected by a strip of copper, instead of having their surfaces soldered directly against each other, and the zinc and the copper are placed in separate cells. This arrangement, indeed, very closely resembles that *là couronne de tasses* of Volta; but it is more compact, and as all the copper and zinc plates are attached to a piece of wood, they can be readily lifted out of the exciting liquid when not in use. This is a great convenience when a continued series of experiments is conducted at short intervals. As the earthenware trough with fixed divisions is liable to be broken, and is rather difficult to manufacture, it has been found more convenient to have the rectangular cells made separately, and to enclose them in a wooden case.

Dr. Babington's form of battery has been very extensively used for the electric telegraph, though made of other materials than earthenware. Most of the batteries of the Electric Telegraph Company were originally constructed in wooden troughs, with partitions of slate made water-tight by means of marine glue. These, again, are being supplanted by troughs made of gutta percha, which are much lighter, and the cells of which can be more effectually prevented from leaking. The plates of these batteries are connected by strips of copper, which are

bent into arches, so as to admit of each plate of a connected pair being inserted into separate cells. The zinc plates are well amalgamated, and are allowed to remain in the cells day and night, the local action being in a great measure prevented by filling each cell with fine sand, and by using sulphuric acid diluted with about twelve parts of water. A voltaic battery, with sand and diluted sulphuric acid, will continue in good action, with occasional additions of acid, for two months before the zinc plates require to be cleaned or re-amalgamated. The consumption of zinc on the numerous and extended lines of the Electric Telegraph Company is very great, the cost of battery-power amounting to upwards of three thousand pounds in a single year.

Batteries in which graphite is substituted for plates of copper have been introduced by Mr. C. V. Walker in working the electric telegraphs of the South-Eastern Railway Company, and with very good results. One of these batteries of twelve pairs, of which a record was taken, was kept in daily action for ninety-seven weeks without having been washed or having the sand changed. It was supplied with about a dessert spoonful of acid water twenty-one times during the period it was in action, and six times with merely warm water. In one instance it did duty for seventy-seven days without having been touched.*

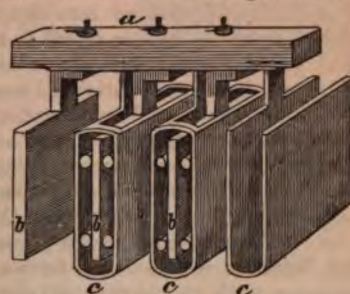


Fig 52.

Dr. Wollaston contrived the arrangement shown in fig. 52 for obtaining the greatest amount of power from a given surface of zinc. The copper plates *c c c* are doubled, so as to expose a conducting surface to both sides of the zinc plates *b b b*. The zinc and copper plates are also brought as close together as possible without actual contact, by which proximity the resistance of the fluid is diminished, and the effect is consequently increased. The plates are secured to a bar of wood, and are kept apart by pieces of cork. With a battery of this kind, consisting of a few pairs of large plates, prodigious heating power is produced, though the intensity of the electricity is too feeble to communicate a shock.

The battery invented by Professor Daniell, the action of which has been previously noticed,† is constructed on a different

* *Jury R* ... he Great Exhibition. † Page

principle. In the voltaic arrangements before-mentioned, the zinc and copper plates immersed in the same cell are liable to have their actions impeded, and ultimately altogether arrested, by the transfer of zinc to the copper surface. The action of the conducting plate is also greatly retarded by the accumulation of hydrogen gas; so much so, indeed, that very frequently, after the first minute that the battery has been put in action, not more than one-tenth of the original power is obtained. In Professor Daniell's battery, the zinc and copper plates are kept apart by means of porous earthenware cells, or by pieces of animal membrane, which, though sufficient to prevent the passage of metallic particles, do not materially interrupt the voltaic action.

Fig. 53 shows an arrangement of a single cell of this kind: C is a copper cylindrical vessel, with a binding screw B, soldered to one edge for the purpose of holding a connecting wire. Into this copper cylinder a porous tube D, closed at the bottom, is introduced; and into the tube is placed a rod of amalgamated zinc Z, with a binding screw at the top. A solution of muriate of soda (common salt) is poured into the porous tube, and the outer copper vessel is nearly filled with a saturated solution of sulphate of copper to which a little sulphuric acid has been added.

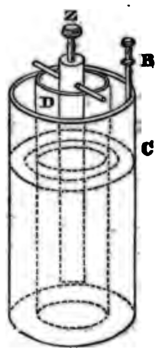


Fig. 53.

When metallic connection is made between the rod of zinc and the copper cylinder, active excitement of voltaic electricity occurs. The oxygen of the saline solution combines with the zinc, and the liberated hydrogen passes through the porous cell to the copper. It does not, however, escape in the form of gas, but it enters into combination with the oxygen of the sulphate of copper, and the metal, being thus deprived of its oxygen, becomes "revived," and is deposited in a metallic form on the inner surface of the cylinder. By the continued absorption of hydrogen by the sulphate, and the deposition of copper, a bright conducting surface is maintained; and this constant renewal of the conducting surface not only increases the intensity of the action, but maintains it with a steadiness that cannot be attained by any of the batteries previously described.

The constancy of action peculiar to this arrangement has obtained for it the name of the "constant battery." To maintain its constancy, the solution of sulphate of copper should, *however,* be preserved in a saturated state by the addition of *crystals of the* metallic salt; and when this pre[illegible] is observed,

iell's battery will continue in action for several days with-
ıch diminution of the original force. A ledge perforated
oles is generally fixed inside the copper cylinder for hold-
ystals of the sulphate, which gradually dissolve and keep
ution in a saturated state.

voltaic arrangement contrived by Mr. Smee deserves
notice from its general utility.
incipal differences between it and
ery of Dr. Babington's arrange-
onsist in the material of the con-
g plate, and in the mode of placing
he conducting plate is made of
foil platinized; that is, a thin
ıg of platinum is deposited on the
by the electrotype process. The
ly-divided particles of platinum
hus cover and adhere to the sil-
esent a greatly enlarged surface
liquid in which it is immersed,
ch means a smaller sized plate
s equally with a much larger one
oth metal. Platinum also being
l less readily oxidized than copper,
ect of the voltaic arrangement is
ned by the greater dissimilarity
two metals. The platinized silver foil is fixed in the centre
oden frame s, and two zinc plates, z z, well amalgamated,
ached to the upper rim of the frame by a brass clamp,
has a binding screw connected with it. By this arrange-
the zinc plates can be very readily removed and cleaned.
s respect a Smee's battery is more convenient than any
its action also approaches a Daniell's battery in constancy.
are important advantages, which render this form of
battery the best that can be used for general purposes.

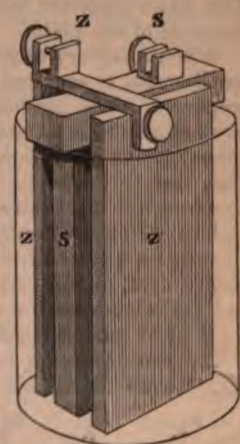


Fig. 51.

substitution of graphite for the platinized silver plates
es to be a still further improvement. With graphite
ting plates there is no occasion for the wooden frame. A
zinc plate, with a binding screw soldered to it, occupies
ntral place, instead of the platinized foil, and two flat
of graphite may be clamped on each side; care being
to insulate the zinc from the graphite by small strips of
hed wood. It will be observed that in this disposition of
paratus with the graphite, the position of the exciting
reference to the conducting surfaces is transposed, as
the propor of each to the other reversed; a sim

plate of zinc being placed between two conducting surfaces instead of the conducting surface being in the centre, with a zinc plate on each side. The difficulty of procuring plates of graphite has prevented the general adoption of this substance in forming voltaic batteries. There is, likewise, an inconvenience attending its use, arising from the want of good connection. The latter objection may, however, be removed by electrotyping the edge of the plates.

When a battery of great power, and occupying comparatively small space, is required, Mr. Grove's arrangement is commonly employed. The intensity of its action depends on associating two metals the most dissimilar in their chemical characters, and exposing one of them separately to the strongest exciting acid. This can only be done by using a porous cell, which keeps the zinc from the destructive action of the powerful acids employed, and to which platinum is exposed in a separate compartment. The porous cell which contains the zinc is filled with diluted sulphuric acid, in the proportion of one of acid to four of water; and the other vessel, with the platinum foil, contains equal proportions of concentrated nitric and sulphuric acids.

The accompanying diagram, fig. 55, represents a section of Mr. Grove's nitric acid battery, in a series of four pairs of zinc and platinum. The outer thick line, A B C D, is an earthenware trough, which is divided into four cells. The dotted lines represent four porous vessels, of a size sufficient to contain about double the quantity of liquid that is contained between the outer surfaces of the porous vessels and the earthenware cells. The dark central lines are the plates of amal-

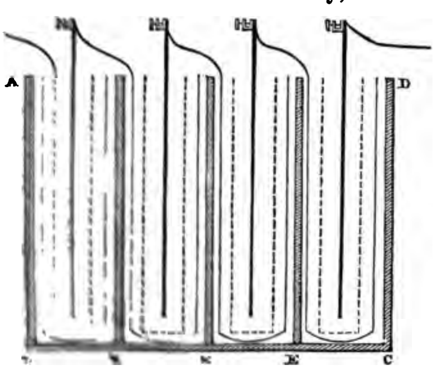


Fig. 55.

[illegible], and the thinner lines that bend round under the [illegible] show the position of the platinum foil, which is [illegible] zinc plate by small screws.

[illegible] diluted sulphuric acid is poured into the porous cells in [illegible] is introduced, and outside the porous cells, in con[illegible] platinum, is the mixture of concentrated nitric and [illegible] acids. Those two acids should be mixed together, in

equal proportions, some time before the battery is used. During the action of this battery there is a copious evolution of suffocating fumes of nitrous gas, for the absorption of which the battery should be provided with a cover, containing quick lime.

With a battery of this construction, consisting of fifty pairs four inches long by two wide, and which does not occupy more space than eighteen inches square, the most powerful effects may be produced. Metal wires are melted into globules, and dissipated into oxides, and a dazzling flame upwards of an inch long is produced between charcoal points.

Professor Bunsen has substituted carbon for platinum, in nitric acid batteries, with good effect. To overcome the difficulty of shaping graphite into the required form, he made a composition of coke and coal in fine powder, which were heated together in iron moulds, and thus formed a solid mass of carbon of the required form. To give further solidity to the mass, it is plunged into a syrup of sugar, afterwards dried, and then subjected to intense heat in covered vessels. The form which Professor Bunsen prefers for his carbon conducting surfaces is cylindrical, and the shape of his battery resembles that of Daniell's. To make a good connection between the carbon and the connecting wire, a ring of copper is fixed round the top of the carbon cylinder to which the wire is soldered. The accompanying diagram shows the several parts of one of the cells of a Bunsen's battery, A being the carbon cylinder, with its copper ring and attached wire, B the porous cell into which it is introduced, C the cylinder of amalgamated zinc that surrounds the porous cell, D is the external earthenware jar, and E represents the arrangement of the whole completed.

E D Fig. 56. C B A

Bunsen's battery is extensively used on the Continent, and it is represented to be, when in good action, nearly equal to *Grove's in power*. and superior to it in constancy. There are

however, two practical objections to the compound carbon conductors that materially diminish the value of this arrangement. In the first place, the nitric acid ascends through the pores of the carbon, and corrodes the copper ring: and secondly, the surface of the carbon cylinders frequently crumble away, and the connection with the wire becomes imperfect.

A very powerful battery, in which cast iron is the negative element, has been contrived by Dr. Callan, of Maynooth, and which has received the name of the Maynooth battery. The cast iron forms the outer cylinder, inside of which there is a porous cell containing the zinc plate. The battery is charged with a mixture of nitric and sulphuric acids in the outer cylinder, and the porous cell is filled with a diluted solution of the same acids. Dr. Callan constructed a battery of this kind of prodigious power. It consisted of 600 cast iron cells, each of sufficient size to hold a porous cell containing a zinc plate four inches wide. With this powerful apparatus an arc of light five inches long was formed between a copper wire and a brass ring. The intensity of the heat, when charcoal points were used, burned the charcoal rapidly away, and a file was deflagrated by the flame, even when the circuit was partially interrupted. Dr. Callan estimates the power of a cast iron battery of his construction to be about fifteen times greater than that of a Wollaston's battery of the same size, and to be one-half more [illegible] than a Grove's nitric acid battery. Dr. Callan has [illegible] proposed to improve the action of his battery by making [illegible] cylinders of sheet tin, coated with an alloy composed [illegible] tin in nearly equal proportions. Upon tin plates [illegible] diluted sulphuric acid has scarcely any action.

[illegible] battery contrived by Mr. Grove must be regarded [illegible] theoretical curiosity than as a practical means of [illegible] electricity. In this battery the only metal [illegible] platinized platinum, thin strips of which are [illegible] partially filled alternately with different [illegible] acidulated liquid. In the original arrange[illegible] hydrogen gases were used alternately, and [illegible] was diluted sulphuric acid. With a series [illegible] about a quarter of an inch wide, one [illegible] a shock was given that could be [illegible] hold of hands, a brilliant spark [illegible], water was decomposed, and a [illegible] effected. Experiments were made [illegible] gases, which were found to pro[illegible] the tubes were charged with [illegible] electric current, nor was there

excited when carbonic acid and nitrogen, or oxygen and ogen, were employed; but with hydrogen and chlorine, or rine and carbonic oxide, the effects were very good. Mr. ve found that there was no action when the platinum was gether immersed in the liquid, with the gases above them; but as soon as the ends of the metal plates were exposed above liquid, electricity was excited. The accompanying woodcut

Fig. 57.

sents the original arrangement of the tubes in the gas ry.

iere are various other arrangements of voltaic batteries, but ave described all those that are constructed on distinctive iples. The object in every case is to obtain from a given tity of the exciting metal the greatest possible amount of nt electricity, without allowing the power to be wasted in ways. The consumption of a given weight of zinc cannot, ay possible combination, excite more electricity than will npose a quantity of water equivalent to that which is nposed by the chemical affinity of the metal for oxygen. , supposing two grains of water to be decomposed in the rating cell, and eight grains of zinc to be oxidized, the ricity generated during the process cannot be more than ient to decompose another two grains of water. The power ned, even by the best arrangements hitherto contrived, m amounts to so much. By increasing the chemical action e liquid on the generating plates, the energy of the battery reased, but most frequently not in proportion to the con- tion of zinc. By bringing the plates in the generating cells r together, the energy of the battery is also increased, by aishing the intervening fluid resistance; but this may be ded with waste of power if the plates be brought too close. onomy of construction is an important consideration when iments are conducted on a large scale, and this must in al *prevent* the adoption of platinum. The orous

cells for the purpose of preventing the deposition of zinc on the conducting-plate is very advantageous, but the high price at which they are sold in this country limits their use, for after a time the pores become clogged and the vessels require to be replaced. This cannot be done in London at a cost of less than ninepence for each, though small. Several contrivances have been adopted to serve the purpose of porous earthenware, such as brown-paper bags, bladder, and sail-cloth, but each has its inconvenience, and there is still wanting some cheap substitute for the earthenware vessels that are now sold at such extravagant prices.

CHAPTER X.

PHENOMENA OF VOLTAIC ELECTRICITY.

Different conditions of Frictional and Voltaic electricity—The two poles of the battery—How to distinguish them—Mystification caused by new terms—Voltaic action immediate and continuous—Its rapid transmission exemplified—Resistance of wires to the electric current—Extraordinary physiological effects—Water-batteries—Intensity of their action—Mr. Crosse's water-battery—Cause of the intensity of water-batteries.

THE power developed by a numerous series of voltaic elements, though in many respects resembling that of an electrical battery of Leyden jars, is in several particulars dissimilar to it.

The difference in the phenomena may be attributed chiefly, if not entirely, to the different degrees of intensity in which the two kinds of electricity are excited. When the intensity of the voltaic battery is increased by the multiplication of the power fifty times, the electricity has not sufficient energy to pass through the smallest space of resisting air in the form of a spark, nor can it exert an attractive force on light non-conducting bodies. Even when the electricity excited by a hundred pairs of large plates has sufficient power to melt metals and to give a strong electric shock, the presence of electricity is not appreciable by a pith-ball electrometer. But when the elements are increased to the number of two or three thousand, as in Mr. Crosse's extraordinary water-battery, the intensity of voltaic electricity becomes so far augmented, that a spark will pass between the connecting wires before contact, and the electrometer is very sensibly affected.

The experiments of Mr. Crosse have, indeed, supplied all that was wanted to show the complete identity of the two forces, and to prove that the difference in their modes of action depends alone on the different degrees of intensity in which they are excited.

The electricity developed at the opposite ends of a voltaic battery appears to bear the same relation to each end of the battery, as the electricity of the inside of a charged Leyden jar bears to the outside. One end therefore is considered to be negative, and the other to be positive.

If the wires from the terminating zinc and copper plates be

furnished with platinum points, and inserted into a glass filled with water, slightly acidulated to increase its conducting power, the water will be decomposed, and resolved into its two elementary gases, bubbles of hydrogen gas rising from one wire, and bubbles of oxygen gas from the other. It will be found, on collecting the bubbles of gas in separate receivers, that the oxygen of the water is liberated from the wire connected with the copper end of the battery, and the hydrogen from the wire connected with the zinc.

In all cases of electro-chemical decomposition, it is also found that the element which collects at the wire connected with the copper corresponds with that which collects at the positive wire of the electrical machine; hence it is inferred that the electricity evolved from the wire connected with the copper end of a voltaic battery is identical with positive frictional electricity, and that the electric current proceeding from the zinc is negative. The copper and zinc ends of a voltaic battery are, therefore, commonly called positive and negative "poles;" the word *pole* having been given to the opposite ends, in consequence of the polar arrangement which, in some instances, is induced by voltaic action.

It is difficult to avoid confusion in speaking of the opposite poles of a voltaic battery. This difficulty arises partly from the apparent generation of the electric force by the conducting-plate, which is comparatively inactive—it is partly to be attributed to the different arrangements of the zinc and copper plates in different batteries—and it is increased by the various names that have been arbitrarily given to the terminal wires.

When the electricity of a single pair of zinc and copper plates is considered, it will be observed that though the electricity is excited by the zinc, the electric current proceeds to the copper, and thence is *returned* by the conducting wire to the zinc. Therefore when the ends of two wires, one from the zinc and one from the copper plate, are inserted into a conducting fluid, the positive electricity will enter from the wire connected with the inactive or negative plate, and at that point the effects of positive electricity will be produced; whilst negative effects will be developed at the wire connected with the generating plate.

The contradiction apparently involved in this statement will disappear, when it is considered that the effects of the electricity excited by the zinc is manifested only in its passage through the wires that communicate with the two plates. The course of the electric current must consequently be from the wire connected with the copper to that connected with the zinc, for that wire serves to conduct it back again to the generating plate. Though *the electricity* appears to proceed from the copper, that metal

operates chiefly as the receiver of the electricity, but the current is assumed always to proceed from the copper to the zinc. The same effect takes place when several zinc and copper plates are combined. The wire leading from the copper end of the battery will be positive, because it is conducting the accumulated electricity on its return to the zinc end; and the other wire will be negative, because it is receiving the flow of electricity which is supposed to pass from the zinc plate to the copper plate, and then to be returned through the communicating wires.

In using a *voltaic pile* or a *Cruikshanks' battery*, mistakes are likely to arise in consequence of the last zinc and the last copper plates not being active, but merely serving as metallic conductors. In a Cruikshanks' battery, for instance, a small cell is generally left at each end without any corresponding plate opposite the last zinc and the last copper; thus, when a conducting wire is introduced at the end where the zinc is the last of the series, it is the same in effect as if the conducting wire were connected to the copper, for the last zinc plate is soldered to the copper only for uniformity, and is altogether inoperative. It would, indeed, be better if the terminal plates were cemented to the end of the trough with a binding screw attached to hold the wire, and then no confusion from that source would arise. The same observation applies to the voltaic pile, the end plates of which should, to avoid mistake, consist of a single zinc disc and a single copper disc.

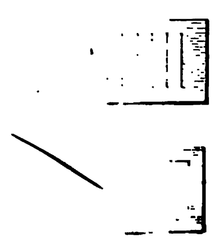
We have before expressed regret at the introduction into electric science of new terms, derived from the vocabulary of a dead language, which serve to mystify, to perplex, and to mislead. The difficulty attending the clear comprehension of the right character of the two ends of the voltaic battery has been by this means increased. To call the extreme copper and zinc plates in a continued series, and the wires connected with them, *the ends of the battery*, expresses clearly and simply the fact, without giving sanction to any doubtful theory. But the word "end" was not deemed sufficiently dignified. "Terminals" sounded better, but the word not being so generally understood it was no improvement. As the action of a voltaic battery produces in some cases a polar arrangement, the name "poles" was introduced, and the "negative pole" and "positive pole" of a battery have become familiar terms. The implied polarization was however objected to, and the word "electrode" has been concocted from the Greek *electron*, amber, and *odos*, a way or door, signifying the *door* into and out of which the electric current passes. As, however, it is questioned by Faraday himself, who sanctioned the term, whether there is any actual entrance

... and whether there is any *current* whatever ... to doubt the appropriateness of the ... signification be admitted, we should much ... an English word.

... "positive" and "negative" were objected to, ... of electricity, of the correctness of which ... With a view to improve the nomen- ... more objectionable terms "anode" and ... introduced, signifying an upward and a ... founded on a fancied resemblance between ... currents round the earth, and the rising ... The "anode" is the electrode at which ... "cathode" the electrode at which the ... composing fluid; the former being in fact ... after the negative end of the battery.

... action of a voltaic battery that the oppo- ... connected by a conductor of electricity; for ... completed through which the electricity ... can pass to the other there is no voltaic ... touch is sufficient to send an electric ... the circuit, however long the wire ... instantaneously ceases when the con- ... The rapidity with which the electric ... and broken, has no ascertained limit; ... by traversing miles of wire.

... close together be drawn with ... substance on a smooth metallic ... connection with one of the poles of ... over them, the electric current ... between the lines, and will ... lines of varnish intervene. To ... a number of straight strokes with a pen dipped in varnish on a piece of tin foil A, fig. 58, and connect the foil with the copper end of a small voltaic battery. On to another strip of tin foil D, connected with the zinc end of the battery by the wire Z, lay a piece of paper B, that has been ... acid and prussiate of ... each end may be drawn at



the same time over the moistened paper and the lines of varnish. By this arrangement the electric circuit will be completed whenever the ends of the bent wire press on the foil and on the paper, and it will be broken as the point passes over the varnish. However rapidly the wire is drawn across the varnish lines by the hand, the making and breaking of contact will be indicated on the paper by a line of blue dots. If the wire be drawn along very quickly the marks will be more faint, but the presence of electric action and the discontinuance of its action may be perceived, even when the connection is made and broken one hundred times in a second.

Though the intensity of voltaic electricity is beyond all calculation less than that of electricity excited by friction, it nevertheless passes along a conducting wire as quickly as the discharge of a Leyden jar. The electric telegraph affords a wonderful illustration of the rapid transmission of voltaic electricity, the signal made at one end being instantaneously repeated at a distance of three or four hundred miles. The effect of the rapid transmission of electricity was perhaps still more strikingly shown in an experiment the author witnessed in the presence of the Court of Directors of the East India Company at Warley Common. A current of voltaic electricity was sent through ten thousand yards of copper wire, and a fuse at one end of the battery was ignited without any perceptible interval of time, as soon as connection was made between the wires; the fuse having been introduced near the end of the circuit that the cause and effect might be seen to be instantaneous. In passing through a length of 2,000 miles, however, a perceptible interval is observed between making connection at one end and the resulting effect at the other.

It is a peculiar property of voltaic electricity, depending on its low degree of intensity, that it will traverse a circuit of 2,000 miles rather than make a short circuit by passing through an interval of resisting air, not exceeding the hundredth part of an inch. Frictional and atmospheric electricity, on the contrary, will force a passage across a considerable interval, in preference to taking a long circuit through wire; or at least the greater portion of it will pass through the air, though some part of the charge will in all such cases traverse the wire.

When quantity is combined with intensity, the resistance offered by a thin wire occasions its fusion. Instances of this sometimes occur during thunder-storms, by the destruction of the galvanometer-coils of the electric telegraph by lightning. To protect the instruments from such accidents, advantage has been taken of the different modes of conduction by voltaic and

frictional electricity. The coil is protected by a lightning conductor consisting of a thick piece of brass in which there is a minute interruption, quite sufficient to prevent the voltaic current from being diverted from the long circuit into the short one, but through which the lightning forces a passage in preference to encountering the resistance of the coil.

These coils are formed of copper wire, nearly as thin as a hair, which is covered with fine silk. The wire, protected merely by this thin insulating covering, is wound on the bobbin, one fold over another, to the length of 300 yards, and yet the voltaic current passes through the whole extent of that fine wire rather than penetrate through the silk that separates one fold of wire from the other.

The intimate relation subsisting between voltaic action and the nervous influence has not latterly excited so much attention as in the early days of the discovery of voltaic electricity. The extraordinary contortions of the limbs on connecting the nerves and muscles of recently killed animals with the poles of a voltaic battery, gave rise to the impression that by the agency of galvanism the vital functions might be carried on after death. This opinion has been to some extent realised by experiment. Dr. Philip succeeded in maintaining the respiration, the pulsation of the heart, and the circulation of the blood, in rabbits from which the spinal marrow and brain had been removed; and he inferred from these experiments "the identity of galvanic electricity and nervous influence."

Some remarkable experiments on the body of a recently-executed murderer are recorded by Dr. Ure, who superintended the arrangements. The experiments were conducted in the theatre of anatomy at Glasgow. The body was that of a middle-sized, athletic, and extremely muscular man. He was taken into the theatre about ten minutes after he had been cut down, his face having at the time a perfectly natural aspect, and the neck not dislocated. The voltaic battery put in requisition consisted of 270 pairs of plates four inches square. On placing one wire of the battery on the exposed spinal marrow on the neck, and the other on the sciatic near the left hip, "Every muscle of the body was immediately agitated with convulsive movements, resembling a violent shuddering from cold. The left side was most violently convulsed at each renewal of the electric contact. On moving the second wire from the hip to the heel, the knee being previously bent, the leg was thrown out with such violence as nearly to overturn one of the assistants, who in vain attempted to prevent its extension."

In another experiment, directed with the view of renewin

the respiratory process, "Full, nay, laborious breathing instantly commenced. The chest heaved and fell; the belly protruded and again collapsed with the relaxed and retiring diaphragm." One of the connecting wires having then been applied to the forehead, the other to the heel, "Every muscle in his countenance was simultaneously thrown into fearful action; rage, horror, despair, anguish, and ghastly smiles united their hideous expressions in the murderer's face. At this period several of the spectators were forced to leave the apartment from terror or sickness, and one gentleman fainted." Dr. Ure was of opinion that if the pulmonary organs had been excited before the spinal marrow had been wounded, the man might have been restored to life.

To produce physiological effects with the voltaic battery, intensity rather than quantity is required. To communicate an electric shock directly from the battery requires a series of fifty pairs of plates, and the shock is then only feeble. Even with a series of one hundred pairs the intensity is scarcely sufficient to overcome the resistance of the outer skin, without dipping the hands into acidulated water or an alkaline solution. The effect of the shock is increased when the surface of contact is enlarged by attaching small copper cylinders to the wires. By that means the imperfect conduction of voltaic electricity through the skin is compensated by the larger surface exposed to its action; it being one of the properties of conducting bodies that a bad conductor of voltaic electricity offers no more resistance to an electric current than a good conductor, provided the size of the former be greater in proportion to its degree of imperfect conduction.

To increase the physiological effects of voltaic electricity, it is necessary to increase the intensity, by adding to the number of plates in the series. Even when the size of the plates is very small, a strong shock and other effects of frictional electricity can be produced, of which there are no indications from a small series of large plates. A battery consisting of a series of 2,100 very small surfaces, was constructed by Professor Daniell, in which the exciting fluid was water, without the addition of any acid. The conducting surfaces of this battery were formed of pieces of copper tube, about one inch long and three-eighths of an inch in diameter, the generating surfaces being pieces of zinc wire soldered to the copper tubes, and bent so as to enter into the centre of each proximate copper tube without touching it. Small separate cups filled with pure water, into which each copper and zinc element was immersed, completed the arrangement. This Lilliputian battery of numerous elements e

current of electricity closely approaching in intensity to that of a Leyden jar. It gave shocks, emitted sparks, affected strongly a gold leaf electrometer, and attracted light substances.

The direct effect of this battery upon metal leaf and fine wire, was inappreciable. The electricity it excited was found closely to resemble that of an electrical machine, and could in like manner be accumulated and made to exhibit the effects of *quantative* electricity. An ordinary electrical battery of Leyden jars could be charged by applying the wires connected with the opposite poles of the battery to the outside and inside coatings of the jars. By this means an electrical charge was communicated to a coated surface of several square feet almost instantaneously. A succession of discharges was obtained to the same extent, but more rapidly, as when the electrical battery was charged by a powerful machine.

Though the full charge which this water-battery was capable of communicating was imparted very quickly, there was an appreciable interval between each discharge of the Leyden jars sufficient to indicate that the voltaic action, though apparently immediate, consists of a succession of efforts rapidly following each other. This is particularly the case when the current has to pass through an imperfect conductor, like the human body; the force seeming to require to be accumulated till it attains sufficient energy to overcome the resistance. When metals form the circuit, the electricity passes as quickly as it is generated, and there is in that case little occasion to increase the intensity by adding to the series of plates.

A water-battery was constructed by Mr. Crosse with much larger surfaces than those of Professor Daniell, and with the cells more carefully insulated. A particular account of it is given by Dr. Noad, who was present during many of the experiments.* It consisted of 2,500 pairs of copper and zinc cylinders, most of which were enclosed in glass jars. They were all well insulated on glass stands, and were ranged on three long tables, well protected from dust and from the light—a situation which experience had shown Mr. Crosse to be most favourable to this peculiar form of the voltaic battery. Thirty pairs afforded a slight spark sufficient to pierce the cuticle of the lip, the hand making the communication being wetted; 130 pairs opened the gold leaves of the electrometer about half an inch; 250 pairs caused the gold leaves to strike the sides of the glass; 400 pairs gave a very perceptible stream of electricity to the dry hand; 500 pairs occasioned that part of the dry skin brought in contact

* *Lectures on Electricity.*

to be slightly cauterized; 1,200 pairs gave a constant small stream of electricity between two wires placed $\frac{1}{100}$th of an inch apart, such wires not having been previously brought into contact. This stream, when received by the dry hands, was exceedingly sharp and painful. A pith ball, a quarter of an inch in diameter, suspended by a silk thread, vibrated constantly between the opposite poles. With 1,600 pairs, the stream of electricity between the two wires not previously brought into contact was very distinct. It might be kept up for many minutes, nor did it appear inclined to cease. The light between charcoal points, even with the whole series, was feeble; there was no flame, nor any approach to it. When the opposite poles of 2,400 pairs were connected with the inner and outer coatings of an electrical battery containing seventy-three feet of surface, a continual charge was kept up; each discharge being attended with a loud report heard at a considerable distance. Each of these discharges would pierce stout letter-paper, and fuse a considerable length of silver leaf, which it deflagrated brilliantly, attended with loud snappings of light more than a quarter of an inch in length. Platinum wire was fused at the extremity, and the point of a penknife was soon demolished. Light substances were attracted at a distance of some inches, and repelled again.

The intensity effects of a water-battery may be considered to be, in a great degree, dependent on the bad conducting power of that fluid. The small quantity of electricity generated by each zinc plate is transmitted from plate to plate to the end of the series, and it is prevented from returning through the liquid in the cells by non-conducting resistance. Thus, though a much less quantity of electricity is generated, it is increased by each successive plate in a greater proportionate degree than when a better exciting, and at the same time a better conducting, fluid is employed. The greater degree of intensity accumulated in a numerous series of elements renders the insulation of the cells more necessary, which is a point but little attended to in voltaic batteries of few combinations, and excited by diluted acids.

A peculiar aeriform body called *ozone* is developed during the excitement of electricity by a water-battery. It is most perceptible, however, during the working of an electrical machine, by a smell resembling that of the slow combustion of phosphorus. This smell had been continually noticed, but it was reserved for Professor Schoenbein of Basle to discover its nature and properties. The same smell is also observable, though in a fainter degree, during the decomposition of water by voltaic electricity, and it is evolved by numerous other compound substances, *when undergoing* decomposition. When phosphorus is allowed

to remain for some time in a moist bottle, the bottle is f
to contain a large quantity of ozone.

This gas has been ascertained to be what is termed by che
an allotropic form of oxygen. It is a powerfully oxidizing ag
so much so, indeed, that a piece of silver leaf, when expos
it, is quickly converted into an oxide, and crumbles into dust
exists in the air, especially in air blowing from the sea, a
supposed to exert great influence in the chemical actions o
atmosphere.

CHAPTER XI.

HEATING AND LUMINOUS PROPERTIES.

Peculiarity of voltaic light—Heating power of large plates—The worst conducting metals the most heated—Influence of resistance in increasing the heating effects —Heat voltameters—Deflagration of metals—The voltaic arc; the intensity of its light and heat; cause of its action.

We have had occasion to speak incidentally of the heating power of voltaic electricity, and of the light emitted on making contact between the wires of the opposite poles of a voltaic battery. We propose to devote the present chapter to a more particular notice of those remarkable phenomena.

The light produced on the sudden disruption of two wires that serve to form a voltaic circuit is not a pure electric spark, but it is due in a great measure, if not entirely, to the conflagration of the metal. The influence of the metal in the production of the light is evident from the different colours with which it is tinged, according to the kind of metals between which the disruption takes place. The spark does not appear excepting at the instant of contact, or when the wires are separated, the intensity of voltaic electricity not being sufficient to overcome the resistance of the smallest film of air until the number of plates in a series exceeds two or three hundred. The heat, however, that is evolved during the transmission of a voltaic current is manifested strongly by a single pair of plates.

The discovery that voltaic electricity possesses the property of developing heat, very quickly followed the discovery of the voltaic pile, and the improved arrangement of it in the *couronne de tasses.* It was almost immediately observed that the passage of an electric current through the communicating wires when very thin, heated and even melted them. It was soon after wards discovered that voltaic combinations of large plates, although they had no greater tension than the same number of smaller plates, developed much more heat. Sir Humphrey Davy found that with a voltaic battery formed of large plates, water could be quickly made to boil, by plunging into it an iron wire *through which a powerful* voltaic current was being transmitted

He had, indeed, previously succeeded in melting steel wire, and in burning leaves of gold, silver, tin, zinc, and copper, when beaten thin.

The further progress of discovery in the heating property of voltaic electricity served to prove more conclusively that electrical action is only exhibited when resistance is offered to the progress of electricity; for it was invariably found that the light and heat evolved in metallic conductors were the most intense when the resistance was the greatest.

Mr. Children was the first who directed attention to the powerful heating effects of large surfaces of copper and zinc combined, in a few series. He made use of a battery of twenty pairs of copper and zinc, each plate having a surface of sixty-two square feet, charged with acidulated water. With this battery he obtained immense heating power, and melted a platinum wire thirty-three inches long and one-fifth of an inch in diameter.

For the purpose of ascertaining by the agency of this battery the different effects produced on different metals of the same length and thickness, he employed various wires to connect the opposite poles of the battery. When a platinum and a silver wire were thus arranged, the platinum, the worst conductor, became red hot, whilst the silver remained cool. Another curious exemplification of the property that the effect is increased with the resistance, was shown by sending the current through a chain made of alternate links of silver and platinum wire, when the platinum wires became red hot and the connecting silver links remained cool.

The effect of resistance in increasing the apparent heating effect may, indeed, be distinctly shown with two pairs of an ordinary Smee's battery. Introduce into the circuit of thick copper wire a small length of very fine steel wire, and on making contact, the steel wire will become red hot whilst the copper wires give no indication of heat.

Liquids as well as solids are heated by the transmission of a voltaic current, and in the case of liquid as of metallic conductors, the worst conductor becomes the most heated, provided the conduction be not so imperfect as to prevent the passage of the current. The following arrangement (fig. 59) will serve to show this effect very satisfactorily. In three wine glasses, *a*, *b*, *c*, pour equal quantities of water, of salt and water, and of a solution of sulphate of copper. Connect them together with bundles of cotton thread moistened with salt and water, and introduce into *a* and *b* the wires connected with the opposite poles of a voltaic battery. The voltaic current

will thus be established through the three glasses of liquid, and after a short time the water in *a* will become some degrees warmer than in *b*, and the latter will be warmer than the sulphate of copper solution in *c*; the degree of heat communicated corresponding with the relative conducting powers of the three liquids.

Fig. 59.

In a column of water traversed by an electric current, the elevation of temperature is greater at the positive pole than at the negative, but it is greatest in the middle. It has also been observed that the development of heat in the interior of a liquid mass placed between the two poles of a voltaic battery may be considerably augmented, by dividing it into several compartments by porous diaphragms of bladder or gold-beaters' skin. For example, if the same voltaic current is made to pass through liquid contained in a glass tube of a given diameter and length; and also through a similar tube of the liquid into which a skein of cotton has been introduced, the latter will be found of higher temperature than the former. This effect is attributable to the cells of cotton wherein the liquid is lodged, forming so many small compartments, separated from each other by diaphragms, which increase the resistance to the passage of the electricity. For the same reason, the stalk of a fleshy plant quickly becomes heated when a voltaic current is sent through it, because the conduction of the electricity through the liquid meets with resistance from the minute cells that enclose the vegetable juice.*

The property which voltaic electricity possesses of heating the substances that conduct it has been applied to measure the relative quantity of electricity transmitted. The first voltameter constructed on that principle was invented by M. Gaspard De la Rive. It consists of a fine platinum wire stretched vertically parallel to an ebony support, to insulate the wire from the other parts of the instrument, so that the current may not be diverted into any other direction. The wire at its lower end is attached to an index, the point of which is directed to a graduated scale (see fig. 60). When the upper and lower parts of the instrument are connected with the poles of a voltaic battery, the platinum through which the current passes becomes expanded by the developed heat, and by acting on the lower end of the

* De la Rive's *Treatise on Electricity*, vo

He had, indeed, previously succeeded in ... indicated on the scale
in burning leaves of gold, silver, tin.
beaten thin. ... sive than the former,

The further progress of discovery in ... thermoscope. Wires of
voltaic electricity served to prove more ... the upper bulb, and
trical action is only exhibited when ... ends being attached to
progress of electricity; for it was inva... connection. When an
and heat evolved in metallic condu... ...ires in the bulb, the air
when the resistance was the greatest ... to it from the wire, and

Mr. Children was the first who ... wer bulb forces it up the
powerful heating effects of large
combined, in a few series. He ma...
pairs of copper and zinc, each pl...
two square feet, charged with a
battery he obtained immense h...
platinum wire thirty-three inches
in diameter.

For the purpose of ascertain...
the different effects produced
length and thickness, he empl...
opposite poles of the battery
wire were thus arranged, t...
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tinum wire, when the ...
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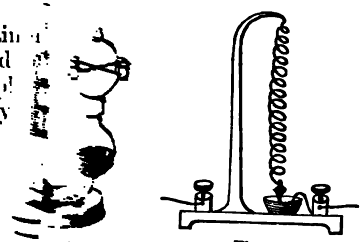

Fig. 62.

... ery minute variations in the
... accompanying woodcut (fig. 61)
... which was invented by

The effect of resista...
effect may, indeed, be ...
ordinary Smee's battery
copper wire a small l... ... by Mr. Hearder, of Plymouth,
making contact, the st... ...eter, he succeeded in measuring
copper wires give no in... ... ...tion that subsists between the

Liquids as well as ... ...ure and its resistance to the
a voltaic current, and ... ...owing table shows the results
ductors, the worst con...
vided the conducti...
passage of the curr...
will serve to show
wine glasses, *a*, *b*.
and water, and of
them together wi...
salt and water, and
with the opposite

Metals.	Heat.	Resistance.
Platinum, . . .	30	5
Iron, ...	30	5
Tin, ...	36	6
Lead, ...	72	12

... however, that the relative degrees of
... the different metals in the foregoing
... inversely with their conducting powers,
... experiments.

..' the voltaic current in expanding the wire 'ı is transmitted is strikingly exhibited by the "rrangement. Suspend over a cup of mercury a spiral .. small weight at the lower end to keep it slightly ..presented in fig. 62. Connect the spiral wire " the poles of a voltaic battery, connect the cup with the other pole, and arrange the wire and the hat the metal point at the bottom may just dip into metal. The voltaic circuit being thus completed the wire, the expansion of it by heat causes the spiral ..t, and to withdraw the connecting point from the The contact being thus broken, the weight elongates it again, and again renews the electrical connection, same effect as before; the weight will thus continue d falling for many hours, each withdrawal of the point mercury being accompanied with a loud snap and a spark.

e metals may be melted and, with the exception of ı, deflagrated with great brilliancy, with a Smee's bat- sisting of twelve quart jars, the zinc plates containing xty square inches of surface on each side. The simplest exhibiting the effect is to attach thick wires from the poles of the battery to the handles of the universal er (fig. 33), to unscrew the brass knobs, and arrange the points above one another, about one inch apart. Having netal leaf into strips, apply the moistened end of a paper piece of wood to the leaf, and thus lift it up and place en the separated wires of the discharger. The instant metal leaf touches both the wires it will deflagrate with lliancy, and with the emission of a crackling sound.

is an observable difference in the colours of the flames fferent metals when thus deflagrated. Gold burns with white light, tinged with blue; silver emits an emerald- ght; copper burns with a bluish-white flame, accom- with red sparks; tin, nearly the same; lead, with a l purple light; zinc burns with a brilliant white flame, to blue, and fringed with red; and mercury burns with rilliant white light.

lengths of thin wires are made red hot, and are melted etched between the battery connections. The lengths y be thus melted are proportionate to the power of the and the thickness of the wire.

utiful effect may be produced by the combustion of iron d mercury with a powerful battery. When a cup of is placed in connection with one of the \ a

[illegible] iron wire is attached to the opposite pole, at the [illegible] the iron wire is brought in contact with the mer[illegible] sparks are dispersed on every side, forming an [illegible] quantity of rays, as if issuing from a magnificent [illegible] splendour. The effect may be continued as long [illegible] dipping the end of the wire into the mercury as [illegible] away. The self-acting arrangement, shown in fig. 62, [illegible] advantageously adopted for this display of brilliant [illegible] action.

[illegible] deflagration of metals by voltaic action, though it appar[illegible] takes place immediately on making contact, is not so [illegible] as the deflagration by frictional electricity. The [illegible] in the rapidity of their actions may be shown by the [illegible] experiments. First, discharge the contents of a bat[illegible] Leyden jars through a very fine wire covered [illegible] It will be instantly deflagrated, the oxide being [illegible] but the silk thread that covered it will be [illegible] Next, send a momentary current from the voltaic [illegible] an equal length of the covered wire by making [illegible] connection of the poles. The effects will now [illegible] former experiment: for the silk will be [illegible] the wire will remain entire. In the first case [illegible] that the particles of metal are dissipated [illegible] conductor of caloric, can be affected by [illegible] second experiment, the slower [illegible] has not time, during the short con[illegible] power and to melt the wire, though it [illegible] the silk.

[illegible] of heat and light evolved by [illegible] by the transmission of a powerful [illegible] points. Sir Humphrey Davy, [illegible] large battery of the Royal Insti[illegible] that when the circuit has been [illegible] pieces of charcoal, they may be [illegible] or three inches without inter[illegible] and that in the space between [illegible] an arch of the most brilliant [illegible] phenomenon he gave the name of [illegible] resembles that of the sun in [illegible] effect of combustion, for it is [illegible] receiver, where no combustion [illegible] water the voltaic arch may be

[illegible] employed, the more brilliant [illegible] may be satisfactorily

wn with a battery of eighty pairs of copper and zinc plates, r inches square, and excited with diluted sulphuric acid. o pointed pieces of boxwood charcoal may be conveniently d to the spring clamps at the ends of the rods of the universal charger, as shown in fig. 63. Two pointed pieces of graphite

Fig. 63.

e been found to answer still better than charcoal. The nts must be brought into contact before they are separated. en they touch, the charcoal becomes heated, and on then dually separating them the light will appear in dazzling lliancy.

With the battery of 2,000 pairs of plates provided by the yal Institution for Sir Humphrey Davy, he succeeded in arating the charcoal points upwards of four inches from each er, without the cessation of the arc of luminous rays. When substance, however refractory to the action of ordinary fire, s brought into this voltaic arc, it became fused; platinum lted in it like wax in the flame of a candle; sapphire, mag-ia, and lime were fused; fragments of diamond disappeared idly, and seemed to evaporate without undergoing previous ion.

The cause of this remarkable phenomenon is not exactly derstood. The light is, most probably, occasioned by incan-cence of minute particles of carbon transmitted from one ce to the other, for during the evolution of the light there n observable transfer of particles of carbon. A small hollow e is made in the piece of charcoal connected with the itive pole of the battery, and on the point of the negatively-nected charcoal a projecting cone is deposited that exactly the cavity.

One of the most beautiful experiments in electric science is the ibition upon a screen of a magnified image of the charcoal nts, when undergoing the action of a voltaic battery. The nts are placed on the field of a magic lantern, and

being thrown on the screen the transfer of the charcoal from one point to the other can be clearly seen without dazzling the eyes. During the action small globules or specs are observed on the charcoal, which are occasioned by the fusion of minute portions of silica it contains. When the voltaic connection is established, the carbon attached to the negative pole of the battery first becomes luminous, but the light from the positive carbon is afterwards the most intense.

A continuous flow of light between the opposite poles of a powerful voltaic battery may be formed by other substances than carbon, but with no other substance can it be obtained so long and so brilliant. M. De la Rive, who made numerous experiments on the voltaic arc, observes: "Having taken for one of the electrodes a plate of platinum, I employed successively for the second electrode points of different substances. With a platinum point the arc is very short, especially if the point is the negative electrode. In air rarefied to about $\frac{1}{10}$th the point could not be separated more than $\frac{1}{25}$th of an inch without breaking the arc. The experiment was made with a Grove's battery of fifty pairs feebly charged. The platinum point becomes very rapidly incandescent when it is positive. Its extremity becomes fused, and falls upon the plate in a spherical globule, whilst when negative it is but little heated. On the other hand, the plate which is then positive, becomes white hot, and runs the risk of being perforated unless it is thick. When a point of coke is substituted for the platinum point over the platinum plate, still remaining positive, an arc double the length of the former one is obtained. The arc itself, instead of presenting as before a cone of light having its base on the plate and its summit on the point, is composed of a series of luminous jets starting from different points of the plate to impinge upon different points of the coke, and the heat developed on the platinum plate was so much increased, that the plate was rapidly melted and perforated. By this we plainly perceive the very great influence that is exercised by the negative electrode, the function of which is far from being merely passive, for we have merely to change the substance of the negative electrode to materially modify all the details of the phenomenon. When the coke is positive and the platinum plate negative, the arc is not so long, especially in air, but the coke point is much heated, and becomes rapidly incandescent throughout."

Iron, copper, silver, and German silver being substituted for the coke and platinum, it was observed that, when one was a point and the other a plate of the same metal, the pointed wire *became incandescent* for a considerable distance if it were con-

nected with the positive pole of the battery, and that it was heated at the extremity only when connected with the negative pole. When mercury was used instead of a metal plate, the mercury was put in a state of great agitation, and rose in the form of a small cone when it was connected with the positive end of the battery, and it presented a cavity beneath the pointed wire when the poles were reversed.

Experiments with the voltaic arc exhibit a further illustration of the fact, that increase of effect is produced by increasing the resistance to the passage of the electric current. When the two points are formed of the same substance, it is the one connected with the positive pole that becomes most incandescent, but when different substances are employed the one that is the worst conductor becomes most heated, whether it is positive or negative. Thus, for instance, when the positive point is silver and the negative is platinum, the latter, which is the worse conductor of electricity, becomes much hotter than the silver.

All these experiments with the voltaic arc serve to prove that the cause of the phenomenon is attributable to the incandescence of particles emitted from the positive point, and the continued action of the battery through the intervening space of air must be owing to the conducting power of those minute invisible particles. In the case of carbon the particles are more abundant but specifically are less conducting, whilst the metal points yield a less copious supply but possessing separately greater conducting power.

CHAPTER XII.

SECONDARY CURRENTS.

The Voltaic current dependent on resistance—Induction of secondary currents on making and breaking contact—Induction of electricity in a separate wire—The direction of secondary currents opposite to primary—Faraday's views of the action of induced currents.

THE manifestation of the presence of electricity, whether excited by friction or by chemical agency, depends, as we have several times had occasion to observe, altogether on resistance to its diffusion. Were there no resisting medium there would be no development of electric force, because it would be neutralized as quickly as generated by unimpeded conduction. A glass rod cannot be excited by friction unless the air be, partially at least, dry and non-conducting; whilst, on the other hand, a metal rod may serve as an electric, if the dispersion of the electricity be prevented by insulating the metal on a glass handle, which resists the flow of the electric fluid. It is resistance, also, that in the same manner induces the manifestation of voltaic electricity. Were it not for the resistance of the fluid in the cells of the battery, which prevents the direct return of the electricity from the conducting plate to the zinc, no voltaic action could be perceived, for the positive and negative electricity would be immediately neutralized. If, for instance, a good conducting medium were established by the introduction of mercury into the bottom of the cells, there would be very energetic chemical action; there would be the excitement of electricity, but it would be inappreciable, because it would be conducted back to the zinc plate as quickly as generated. It is evident, therefore, that without a resisting medium electricity could not be excited.

It is equally true, though not at first so evident, that the exhibition of electric force, when excited, depends on the resistance made to its passage through the bodies on which it acts. Lightning passes imperceptibly through a thick metallic rod, but shivers into pieces an imperfectly conducting oak. The voltaic current also passes, as we have seen, through a thick conducting wire without any observable effects; but when the same current is obstructed by a thinner wire it develops heat.

Even in electro-chemical decomposition, it is found that the decomposing effect is diminished when the liquid undergoing decomposition conducts electricity too freely.

Another class of phenomena depending indirectly on the influence of resistance in increasing the effects of electrical action is still more remarkable. All the preceding phenomena which have been noticed are caused by the direct action of the voltaic current in its circuit from one end of the battery to the other; but in addition to the direct effects of the electricity thus put in action there are other voltaic currents, excited by induction, which are in many cases more energetic than the primary electric current that induces them. We shall have to notice the peculiar character of this inductive action more particularly when considering the phenomena of electro-magnetism, but there are some points which come appropriately within the present division of our subject.

When contact is made and broken with the connecting wires of a single pair of plates, the wires used being thick and the circuit short, scarcely any spark is visible on breaking contact; but when the current passes through a long wire, a bright spark, accompanied by a snapping noise, will be seen when the contact is suddenly broken. The effect increases to a certain extent with the length of the wire, and if it be twisted into a spiral the spark is more bright and the snapping sound is louder.

Such a result is directly at variance with the presupposed action of a voltaic current. As the resistance increases with the length of the wire, it might have been confidently predicated that the indications of electric force would decrease with the diminution of the quantity transmitted instead of being in any way increased. The phenomena of this anomalous action of the voltaic current in long resisting wires have been investigated by Faraday with the care and ability manifest in all his experimental researches, and he has succeeded in eliciting from them some highly interesting facts.*

It was ascertained in the course of his experiments that up to a certain point the spark on breaking contact becomes brighter, and the electric development stronger, in proportion to the addition to length of the conducting wire. The point to which this effect was obtained was limited nevertheless by the diminished quantity of electricity that could pass through the longer wire, for after elongating the wire for several yards the resistance of the metal so far diminished the quantity of electricity it could transmit as to interfere with the effect. Having, however,

* *Experimental Researches*, ᵱ

obtained the maximum result that mere addition to the length of the wire could give, the effect was much increased by twisting the wire into a spiral; the wire having been covered with cotton for the purpose of insulating one fold from another.

The brightness of the spark and the loudness of the snap were still more augmented by the insertion of a bar of soft iron within the coil of covered wire. It was evident, therefore, from these variations in the effect, while its resistance to the electric current remained the same, that the increased force could not be attributed, as was at first conceived, to momentum acquired by the electric fluid in its transmission through the wires.

Another remarkable fact disclosed in these researches was, that the extra current could be developed in a second and altogether separate wire placed parallel to the first; and that when the power was thus imparted to the second wire, the primary one, through which the direct action of the battery was communicated, appeared to be no longer specially affected on breaking contact.

In the earliest mode of making this experiment a long wire covered with cotton was stretched alongside the wire through which the voltaic current passed, and the two ends were brought together. It was then found that when contact with the battery was broken by the primary wire, a bright spark was emitted at the junction of the secondary wire, which had no connection with the battery. This manifestation of electricity in the second wire appeared to be derived by a transmission of the action from one wire to the other, for only a very feeble spark was visible in the primary wire when the second one was placed beside it; and on removing the second wire the bright spark was restored to the first when contact with the battery was broken.

From these experiments it appears that the bright spark in the single long wire exhibits the electricity that would be induced in a second wire placed near it, and as each additional length of wire induces an increased amount of electricity, we may form some idea of the cause of the effect being increased by lengthening the wire, even though the quantity of electricity actually transmitted is diminished by the increased resistance. When the long wire is wound into a close spiral it becomes still more effective in producing sparks on breaking contact, because, there is then a mutually inductive action in the convolutions of the wire, each one assisting to increase the effect of the other.

Dr. Noad, in repeating Faraday's experiments, tried the effect

on a long flat coil of copper, consisting of strips one inch wide and 234 feet long. At intervals of twenty-five feet throughout the whole length of the copper ribbon, wires were soldered, supporting small cups of mercury, so that the voltaic current could be readily sent either through the whole length of the coil or through any portions of it. When a pair of plates contained in a pint cup were employed, the maximum effect was produced after the current had traversed about 80 feet. When the size of the pair of plates was reduced, the maximum effect was not produced until after traversing 250 feet of copper ribbon. Large plates being tried, the brightest spark was obtained after traversing only 50 feet. With this coil shocks could be obtained on breaking contact; but the strength of the shocks did not correspond with the brightness of the spark. When the large plates were employed, a very slight shock was perceptible after the current had traversed only 50 feet, but when it passed through a length of 250 feet, the shock was strong enough to be felt at the elbows, though the spark was comparatively feeble.

These results correspond with other experiments which prove that when the length of the coil is increased and the battery continues the same, the deflagrating power decreases whilst the intensity of the shock increases. This increase is limited, however, to the point where the resistance to the passage of the current diminishes too much the quantity of electricity transmitted.

By increasing the intensity of the battery the action of the short copper ribbon coil decreases, but the effect is greatly magnified when the length of the coil is increased in proportion to the additional number of battery plates. It has been found, for example, that a Cruikshanks' battery of sixteen pairs produces scarcely any effect when transmitted through a short ribbon of copper, but when sent through five miles of copper wire $\frac{1}{17}$th of an inch in diameter, it gives shocks too strong to be borne. A very diminutive battery, composed of a series of six pieces of copper wire with zincs of corresponding size, when discharged through the five miles of wire, gave shocks to twenty persons joining hands together, though a single pair of larger plates communicated scarcely any shock.

If any further proof were required that the currents thus induced are not dependent on accumulated energy in the conducting wire, it is afforded by the additional fact, no less curious than any other of these remarkable phenomena, that the secondary currents proceed in the reverse direction of the primary that induce them. If, for instance, the second wire be placed alongside the primary one, when the latter is transmitting a current from

left to right; the induced current in the second wire, when contact is suddenly broken, will be in the direction from right to left.

A simple apparatus contrived by Faraday exhibits most satisfactorily the phenomena of induced currents, and the changes of their directions. A pair of zinc and copper plates, z c, were immersed in diluted acid; G and E represent cups of mercury, wherein contact was made and broken with the wires A B, which formed a circuit through a long conducting wire; two wires N P, were attached to the long circuit, and could be brought into contact at x, or have an apparatus interposed there to indicate the direction and force of the induced currents. To produce a spark in the cross wire junction, a piece of soft iron was placed in a helix at D, and the ends of the cross wires were rubbed lightly together whilst contact was broken at G or E by raising the wires A or B quickly from the mercury. In such circumstances a bright spark passed at x at the moment of breaking contact, none occurring at G or E; this spark exhibited the luminous passage of the extra current through the cross wires. When there was no contact at x, then the spark appeared in the mercury cups when contact was broken; the extra current forcing its way through the cell of the pair of plates. On introducing a fine platinum wire at x no visible effects occurred so long as the contact was continued, but on breaking contact at G or E the fine wire was instantly ignited. Chemical decomposition was also exhibited by the cross wire current by the introduction into the circuit of a piece of paper moistened with a solution of iodide of potassium; but the points at which the iodine and the potass appeared were the reverse of those at which they were disengaged by the direct current. This proved that the momentary current induced in the cross wires on breaking contact was in the contrary direction to the primary current. The same fact may be more clearly shown by the introduction into the circuit of the cross wires of a galvanometer, an instrument which will be more particularly noticed with electro-magnetic phenomena.

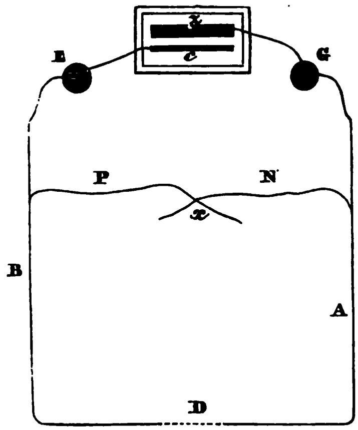

Fig. 64.

The effect of induced currents is perceptible, even through thick partitions of non-conducting substances, and may be communicated to a third and to a fourth coil. In fig. 65, *a* represents a coil of copper ribbon, one end of which is attached to the copper plate of a voltaic battery, and the other end is loose, to facilitate the rapid making and breaking of contact. For this purpose, a rasp may be fixed to the binding screw of the zinc plate, and by drawing the loose end of the copper ribbon over it, there will be a rapid succession of contacts and interruptions.

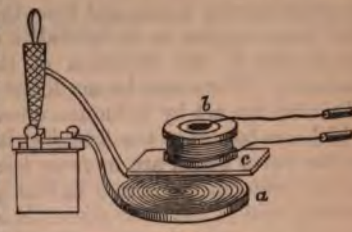

Fig. 65.

A plate of glass *c*, or a board, may be laid upon the coil, and above it place a helix of fine covered copper wire, to the ends of which two brass handles are attached. When contact with the battery is rapidly made and broken, with the loose end of the copper ribbon, a series of severe shocks will be felt on taking hold of the brass handles, though it is quite evident that no portion of the electricity from the battery can be directly transmitted through the helix of wire.

This experiment appears the more wonderful, when the induction of electricity takes place in two separate rooms, by suspending the coils on opposite sides of the partition. A coil of copper ribbon of about 100 feet long should be connected with the battery in one room, and a helix of about 300 yards of fine wire, with handles attached, should be placed on the opposite side of the partition, in the room adjoining.

The induction of electricity may be exhibited passing through several coils of copper ribbon and copper wire detached from each other:—Thus, upon the first coil there may be laid a second, which is connected with a third, and upon the third a fourth detached coil may be laid, in which electricity will be induced when contact is made and broken through the first coil.

In these variations of the modes of inducing electricity in detached coils of wire, the electricity induced may be developed either in a state of intensity, so as to give shocks, or in the condition in which it is excited in the primary coil by a single pair of plates, according to the kind of coil employed. When the secondary coil consists of copper ribbon or thick wire, the effect will be that of quantity, but when a long coil or helix of fine wire is substituted, *intensity* effects are produced.

In addition to the induction of an electric current

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CHAPTER XIII.

ELECTRO-CHEMICAL DECOMPOSITION.

Decomposition of water—Transference of the elements through intermediate vessels—Faraday's hypothesis—Infinitesimally small particles acted on—Suspension of chemical affinity by voltaic action—Supposed identity of chemical affinity and electricity—Decomposition of the alkalies—Remarkable combustion of paper by voltaic action—Decomposition of metallic salts—Definite action of electro-chemical force—Electro-chemical equivalents—Absolute quantity of electricity in bodies—The quantity in a grain of water estimated—The chemical voltameter.

We have already noticed that a succession of sparks from an electrical machine, or a succession of discharges from a small Leyden jar, can produce the decomposition of many compound substances; and that in such decompositions certain elements attach themselves to the positive, and others to the negative, wires. These effects, and this peculiarity of action, which are observable only on a very limited scale in frictional electricity, are largely and powerfully developed by the voltaic battery.

The decomposition of water affords one of the simplest and most instructive exhibitions of the decomposing power of voltaic electricity. A single pair of plates, when excited by diluted sulphuric acid, is not sufficient to produce the effect. The addition of another pair of plates imparts the required intensity, but only sufficiently to exhibit the phenomena of decomposition in a feeble manner. With a combined series of twelve cells most compound substances may be resolved into their elementary constituents very satisfactorily. When the connecting wires from the opposite poles of such a battery are inserted into a glass containing acidulated water at a short distance apart, small bubbles of gas will be seen to collect on the wires, and to rise in quantities to the surface. If the wires be platinum, which metal does not combine with the oxygen of the water, there will be a copious discharge of bubbles from each wire; but if the wires be copper, the oxygen gas will combine with the wire connected with the positive pole, and the hydrogen gas only will be evolved from the other wire.

The form of apparatus represented in fig. 66 is well adapted for the collection of the products of the decomposition of [illegible] *Two glass tubes*, A, B, closed at the top, are filled wit[illegible]

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tubes. The copper wires
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with platinum. The
the battery are connected
apparatus by the binding
When the battery is put
a continued discharge of
gas takes place from the
the two wires, which, rising
the water, collect at the
each tube. The quantity of
ved at the negative con-
surface exceeds that evolved
positive surface in the pro-
of two to one, the former
hydrogen gas and the latter
in the exact proportions in
that, when chemically com-
constitute water. When the
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ucted, it is accompanied with
of the two gases, even when
vessels.

2, 3, containing acidulated
connected with filaments of
and introduce into the two
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rangement. When the voltaic

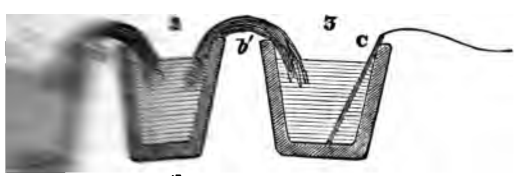

Fig. 67.

positive surface, to z the negative,
No. 3, and hydrogen in No. 1, in
they were liberated when the wires

were inserted in the same vessel. Under these circumstances it will be observed that the hydrogen element of the particle of water decomposed, which is separated from its association with oxygen at C, must pass through the filaments, b', through the fluid in the central vessel, through the second filaments, b, and through the water in glass 1 to Z, where it is evolved. No variation in the amount of battery power employed produces any alteration in the proportions of the gases evolved. The only difference attending the increase of the electric force is to increase the quantity of the gases, the proportions being in all cases those that combine together to form water.

If we assume that the process of decomposition is strictly limited to the same particle of water, and that the separation of its two elements takes place either at C or Z; that portion of the elemental gas which appears at the other wire must traverse invisibly through the three vessels, must rise through the two bundles of filaments, and descend again, without any portion of it escaping. But according to the view of voltaic decomposition taken by Faraday, as already explained,* the process is not confined to a single particle of the fluid, but each particle in the chain of communication is decomposed. Thus, commencing at C (fig. 67), the particle of water decomposed yields up its oxygen at that point, and the gas rises directly to the surface. The adjoining particle of fluid is also decomposed, but latently—the oxygen separated from that second particle instantly combining with the hydrogen liberated from the first, and parting with its own atom of hydrogen to the next particle. This transfer of the hydrogen element is continued through all the particles of fluid in succession until it arrives at the other battery termination, where, the series of decompositions being ended, the hydrogen is liberated, and rises to the surface as a bubble of gas. According to this hypothesis, which has received very general acceptation, the hydrogen liberated in bubbles at one wire is not the same that was associated with the oxygen evolved at the other pole, but there is a complete cycle of voltaic changes, each particle of fluid in the chain of communication having undergone decomposition and recomposition with different, though exactly equal, atoms of the same element.

The particles of water acted on during decomposition must be infinitesimally small. The actual size of the ultimate particles of water has not been ascertained, but some notion of their extreme minuteness may be formed by considering the results of decomposition. A bubble of hydrogen gas the one hundredth

* Page 143.

part of an inch in diameter is distinctly visible by the naked eye, and one million of such bubbles would be contained in a cubic inch. Fifty of such cubes would weigh only a single grain; and taking into calculation the oxygen element of the water, the evolution of a bubble of hydrogen gas $\frac{1}{100}$th of an inch in diameter indicates that a particle of water has been decomposed which could not have weighed more than the sixteen-millionth part of a grain. By the aid of a lens a bubble of gas the one-hundredth part of an inch in diameter seems capable of division into many other globules, so that we are able to observe a result from the decomposition of a particle that could not have weighed the one-hundred-thousandth part of the sixteen-millionth of a grain.

The transfer of the elements of the body undergoing decomposition by voltaic agency is illustrated in a still more remarkable manner when solutions of salts are operated on. The arrangement of the three glasses with asbestos connections (fig. 67) being retained, fill glass 1 with a solution of muriate of soda (common salt), pour a solution of ammonia into 2, and an infusion of litmus into 3. It will be found that under the influence of the voltaic current the muriatic acid combined with the soda in No. 1 will be transferred through the ammonia without combining with it, and will be collected in the glass containing the litmus, as will be indicated by colouring it red. In this case, therefore, it will be observed that the acid separated from the salt in No. 1 is conveyed through a solution for which it has, in ordinary circumstances, a strong chemical affinity; but under the influence of voltaic electricity the action of chemical affinity appears to be suspended.

In the same manner the elements of numerous other compound substances may be transferred through solutions of alkalies or acids without exhibiting any disposition to combine.

This peculiar influence of the electric current is confirmatory of Faraday's hypothesis respecting the mode of electric conduction through fluids. By that hypothesis the apparent suspension of chemical affinity in the intermediate vessel is attributed to the continued transfer of the acid from particle to particle to the fluid with which it ultimately combines, no free acid being actually liberated till the chain of connection is terminated by arriving at the opposite pole of the battery.

The powerful influence of voltaic electricity in controlling chemical affinities led Sir Humphrey Davy to infer, that chemical affinity is itself a modification of electric attraction, and that those bodies which combine most energetically possess inherently, and in the greatest degree, positive and negative electricities.

Considering, therefore, chemical affinity and electricity to be identical, he conceived that the voltaic battery would afford the means of separating the most intimately combined elements by overpowering the attractive force with which they are held together. Acting on this opinion, he applied the power of the battery to the alkalies, which he and other chemists had predicted to be compound substances. The result of these investigations constitutes one of the greatest triumphs of analytical chemistry; for by this means those important substances, the earths and alkalies, were discovered to be oxides of peculiar metals, distinct in many of their qualities from any of the metallic bodies previously known.

The battery power employed by Sir Humphrey Davy was equal to that of 274 pairs of plates four inches square; but even with this powerful apparatus it was not till after numerous failures that he succeeded in decomposing potass. The difficulty experienced was to bring the voltaic influence to act upon the alkali; for in a dry state the non-conducting property of the potass stopped the electric current, and when dissolved, the power of the battery was spent in the decomposition of the aqueous solvent. To apply the electric force to the alkali itself, Sir Humphrey Davy adopted the expedient of making a crystal of potass transmit a current by the moisture of the breath on its surface. This had the desired effect, and the appearance of a globule of metal (potassium) at the negative pole of the battery was a glorious reward for his intelligent and persevering investigations.

The decomposition of the alkalies does not, however, require a powerful voltaic arrangement. This fact was experienced by the author in a somewhat annoying manner when experimenting with the copying electric telegraph, the action of which depends on making marks on paper by electro-chemical decomposition. The paper was well moistened with a solution of prussiate of potass in diluted nitric acid, and the voltaic current passed through the paper from a steel wire connected with the positive pole of the battery. The effect intended to be produced was to decompose the prussiate, and to cause it to combine with the iron of the wire to make a blue mark on the paper. The battery power employed consisted of two troughs of a Cruikshanks' arrangement, each containing fifty pairs of plates of two inches square. With this battery the paper was not only marked with a deep blue line as the steel wire was drawn along, but it was actually set on fire, and a small bright flame accompanied the steel. The *cause of* this combustion was at first perplexing, *as paper can* [illegible] ignited by the direct action of vo

...owerful. The smell of hydrogen gas shortly
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... small in quantity as it was, had decomposed
... solution in the paper; and as quickly as
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... metallic salts by voltaic electricity
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... of copper by the voltaic current,
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... instance, the hydrogen that is disen-
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... the negative pole of the battery, com-
... that retains the metal in the form of a
... the copper—because there is a greater
... and hydrogen than between the
... The copper being thus liberated from
... oxygen, is deposited in a pure me-
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... immersed in the solution of sul-
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... of gas, but it combines with a
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... particle of water, whilst the
... oxygen, is deposited over the
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decomposition of the sulphate of copper held in solution, but by the action and reaction of the oxygen and hydrogen liberated from the decomposed water.

There is great difference in the facility with which different compound substances yield up their elements to the controlling force of voltaic action. Iodide of potass may be decomposed by a single pair of plates feebly charged. Muriatic acid and diluted sulphuric acid may be decomposed with a single pair when the energy is increased by nitric acid, but a combination of three or more plates is generally required to produce decomposition in other bodies. This difference in the facility with which different bodies may be decomposed by an electric current is attributed to the different intensities of their chemical affinities, those substances whose atoms are held together by the strongest affinities offering greatest resistance to the decomposing force.

The interesting and important fact has been clearly established by Faraday, that electro-chemical force is definite in its action, and that the chemical power of a current is in direct proportion to the absolute quantity of electricity that passes. The expression of the theory by Faraday is, "that the chemical decomposing action of a current *is constant for a constant quantity of electricity*, notwithstanding the greatest variations in its sources, in its intensity, in the size of the electrodes used, in the nature of the conductors (or non-conductors) through which it is passed, or in other circumstances." *

The demonstration of this theory by numerous experiments tends strongly to confirm the opinion, that electricity and chemical affinity are the same force differently modified; for it is found that the amount of decomposing effects in all substances agrees very closely with their chemical equivalents.

To those not acquainted with the nature of chemical combinations, it may be desirable to state, that the elements of bodies always unite in definite proportions. For instance, eight atoms of oxygen unite with one of hydrogen to form water, and one atom of oxygen combines with five of potassium to constitute potass; and those elements will not combine in any other proportions. Many elementary bodies unite in various degrees to form different substances, but those proportions are always multiples of the first, and for the constitution of any given substance they will only combine in constant definite proportions. For example, if oxygen and hydrogen gases are mingled together in the proportions of ten to one, and are then exploded in a close vessel, it will be found that chemical com-

* *Experimental Researches*, series vii.

bination has taken effect only between those quantities of the gases required to form water, and that the two portions of the oxygen in excess remain in the vessel not affected by the explosion.

The law by which the combination of elements is regulated in definite proportions to constitute any single substance, is found also to extend reciprocally to all substances whatever. The operation of this law is clearly exemplified in the mutual action of acids and alkalies. Thus, six parts of potass neutralise five of sulphuric acid, and four parts only of soda produce the same effect. These proportions of six to four prevail in the relations of potass and soda to all the acids; and this being known, the quantity of either required to saturate any other acid can be ascertained without experiment. For instance, as the saturating power of soda for sulphuric acid exceeds that of potass in the inverse proportion of four to six, and it being known that 4·4 parts of potass saturate five of nitric acid, it is easily computed that as 6 : 4·4 : : 4 : 2·93; the number 2·93 representing the parts of soda equivalent to potass in saturating nitric acid. The equivalent proportions in which all bodies combine with one another may thus be computed, after having determined experimentally the proportions of one or two combinations.

The amounts of electric force required to separate the elements of bodies from their combinations, correspond in a remarkable manner with the chemical equivalents of the same bodies. For instance, 8 parts by weight of oxygen, which combine with 1 of hydrogen to form water, combine in the proportions of 32 with copper, 58 with tin, and of 103 with lead; and the same amount of electric force that is required to separate 8 parts of oxygen from water, will, by secondary action, separate copper, tin, and lead from their solutions combined with oxygen in the proportions of 32, 58, and 103; the numbers corresponding with their chemical equivalents. So closely have these numbers been found to agree in numerous experiments, that electricians do not hesitate to apply the more strict results of direct chemical analysis to the correction of the results of electro-chemical decomposition.* In reference to this subject, Faraday observes,—"I think I cannot deceive myself in considering the doctrine of definite electro-chemical action as of the utmost importance. It touches by its facts, more directly and closely than any former fact or set of facts have done, upon the beautiful idea that ordinary chemical affinity is a mere consequence of the electrical attractions of the particles of different kinds of matter; and it will probably lead

* *Experimental Researches*, series vii.

us to the means by which we may enlighten that which is at present so obscure, and either fully demonstrate the truth of the idea, or develop that which ought to replace it."

The discovery of the law of the definite action of electro-chemical force, and that the chemical power of an electric current is in direct proportion to the quantity of electricity that passes, has shown the way to the determination of the absolute quantities of electricities belonging to different bodies in their natural states. This interesting subject of inquiry is opened by Faraday in the seventh series of his invaluable *Experimental Researches in Electricity.* "Considering," he observes, "this close and two-fold relation, namely, that without decomposition transmission of electricity does not occur, and that for a given definite quantity of electricity passed, an equally definite and constant quantity of water or other matter is decomposed; considering also that the agent, which is electricity, is simply employed in overcoming electrical powers employed in the body subjected to its action; it seems a probable and almost a natural consequence, that the quantity which passes is the *equivalent* of, and therefore equal to, that of the particles separated; *i. e.*, that if the electrical power which holds the elements of a grain of water in combination, or which makes a grain of oxygen and hydrogen in the right proportions unite into water when they are made to combine, could be thrown into the form of a current, it would exactly equal the current required for the separation of that grain of water into its elements again."

The enormous quantity of electric power contained in a single grain of water is exemplified by the following experiment. Two wires, one of platinum and one of zinc, each one eighteenth of an inch in diameter, placed five-sixteenths of an inch apart, and immersed to the depth of five-eighths of an inch in acidulated water, consisting of one drop of oil of vitriol, and four ounces of distilled water, and connected at the other extremity by a copper wire eighteen feet long and one-eighteenth of an inch in thickness, yields as much electricity in little more than three seconds of time as a Leyden battery charged by thirty turns of a very powerful electrical machine in full action. This quantity, though sufficient if passed at once through the head of a cat to kill it, is evolved by the action of so small a portion of the zinc and water, that the loss of weight sustained by either is inappreciable by the most delicate instruments.

By continuing the experiment until a grain of water was decomposed, it was ascertained that one grain of water requires for its decomposition a continued current of electricity for three *minutes and three* quarters, which current must be powerful

enough to retain a platinum wire $\frac{1}{104}$th of an inch in thickness red hot in the air during the whole time. Making a comparison by the loss of weight of zinc oxidized during the action, it appears that 800,000 such charges of a Leyden battery as that referred to would be necessary to supply electricity sufficient to decompose a single grain of water. Thus, "zinc and platinum wires one-eighteenth of an inch in diameter and about half an inch long, dipped into dilute sulphuric acid so weak that it is not sensibly sour to the tongue or scarcely to our most delicate test-papers, will evolve more electricity in one-twentieth of a minute than any man would willingly allow to pass through his body at once. The chemical action of a grain of water upon four grains of zinc can evolve electricity equal in quantity to that of a powerful thunder-storm." *

In further proof of the high electric condition of the particles of matter, and of the equality of proportions of the electricity inherent to them with that necessary for their separation, Faraday carefully collected the results of the action of an amalgamated zinc plate and a plate of platinum when immersed in diluted sulphuric acid in the proportion of 1 of acid to 30 of water. The quantity of oxygen and hydrogen gases evolved measured 18·232 cubic inches; equal in weight to 2·3535544 grains, which was therefore the weight of the water decomposed. The weight of the zinc plate was diminished 8·45 grains; and 2·3535544 grains, the weight of the water decomposed, is to 8·45, the quantity of zinc oxidized, as 9 is to 32·31. These numbers correspond with the equivalent numbers of water and zinc; which shows that for an equivalent of zinc oxidized, an equivalent of water was decomposed.

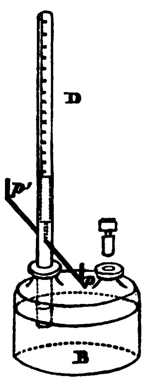


Fig. 68.

The decomposing power of electricity has been employed as a measurer of the strength of a voltaic current. The fact that the amount of decomposition is proportioned to the quantity of electricity being taken for granted, it is only necessary to measure the quantity of gases evolved from water within a given time, to determine the force of the electric current. Instruments of this kind were contrived by Faraday, and were frequently used by him in his experimental researches. Fig. 68 represents the form of the instrument suitable for general experiments. A graduated tube D, of even bore, about one quarter of an inch diameter,

* *Experimental Researches.*

is ground or cemented into one of the openings of a two-necked bottle, B. Two platinum wires, $p\,p'$, are fused into the glass and penetrate within the tube, where they are connected with two small platinum plates that do not touch each other. If the bottle be two-thirds full of diluted sulphuric acid, the fluid will fill the tube when the bottle is inverted, and will not flow out when again placed upright. An electric current being then passed through the tube by connection with the wires $p\,p'$, the gases evolved against the plates collect at the top, and the quantities are measured by the displacement of the water. When the instrument is in use, the stopper is taken out of the second opening, to allow the enclosed air to escape as the water descends from the tube.

CHAPTER XV.

MAGNETISM.

[illegible] and differences—The [illegible]—The force of [illegible] of the poles—Induc- [illegible] magnetic power—Methods of [illegible]—The greatest force [illegible] in a magnetized steel bar— [illegible]

[illegible] related, that it is [illegible] the other. This is [illegible] voltaic electricity [illegible] magneto-electricity, [illegible] commonly used for [illegible] measuring the force of voltaic [illegible] on the communication of [illegible] It has been thought desirable, [illegible] electro-magnetism, [illegible] the character and action [illegible]

[illegible] magnetism, we perceive, at [illegible] difference in the manner in [illegible] that of electricity are developed. [illegible] in bodies becomes manifested only [illegible] and though almost every substance [illegible] the conditions requisite for its [illegible] of frequent occurrence: conse- [illegible] few, unconnected, and evanes- [illegible] they were collected together in [illegible] to form the basis of a distinct [illegible] case was different. The attrac- [illegible] when once observed, was sure to [illegible] of the force afforded ample [illegible] to determine its character [illegible] piece of loadstone naturally [illegible] in similar places; and when [illegible] communication to steel [illegible] was unlimitedly extended.

us, though the substances in which the property of magnetism developed and excited are very few, the permanency of the ce caused it to be extensively known and studied before the enomena of electricity had attracted much observation.

Loadstone, which is commonly considered the source of the agnetic power, is one of the ores of iron, compounded of iron d oxygen, and it is found in many veins of that metal in rious parts of the world. The discovery of it has been attri-ted to a shepherd named Magnes, who remarked its attraction his iron crook, when tending his flock on Mount Ida, and om whom it is supposed the name of magnet is derived; ough, according to other accounts, the loadstone first came om Heraclea, in Magnesia, and one of its ancient names was *pis Heracleus*. It is mentioned by Plato and Euripides as the Herculean stone, because it possessed the power of commanding on, the strongest of metals. The best magnetic iron ore comes rom China.

The attractive power of loadstone for iron enables it to lift masses of that metal several times exceeding its own weight. The natural magnet, however, is seldom used; for steel bars, to which the power can be communicated, are much more con-venient for experiments, and may be rendered more powerfully attractive than the loadstone in its natural condition. In describing the phenomena of magnetism we shall, therefore, seldom have occasion to notice the natural magnet, as the requisite experiments illustrative of the actions of magnetic power are best shown by artificial magnets.

The most remarkable property of a magnet is the power it possesses of attracting iron, to the exclusion of nearly all other substances. The metals nickel and cobalt are, indeed, also attracted by the magnet, but in so much lower a degree that the power, practically speaking, may be said to be limited to iron.

The actual nature of this force is as inscrutable as that of any of the other invisible forces of Nature. It possesses, at the same time, some remarkable properties which are not common to others. One of these peculiarities is the unimpaired exercise of the force through solid interposed substances of all kinds, with the exception of iron, nickel, and cobalt. If a needle be laid upon a plate, or upon a piece of board or a sheet of copper, and the end of a magnet be brought near the under surface, the needle shifts about on the top of the plate, following the move-ments of the magnet, and is quite as strongly attracted towards it as if there were no substance interposed.

Another and very important characteristic of magnetic attrac-

tion is *polarity*. The attractive power varies very materially in different parts of the same bar of magnetized steel. Near the two ends it is the strongest, from which points the force diminishes very rapidly towards the middle, where no attraction whatever exists. This limitation of the power to the two ends is clearly perceived on placing a magnet on the table and touching it with a key on different parts. It will be found that at the centre of the bar there is no perceptible attraction, but that as the key is brought nearer to either end, it is attracted more and more strongly till it reaches the extremity of the bar. The increase in the attractive power does not proceed in regular gradation from the centre. It is very slight at some distance from it, and continues increasing in a small degree till the key approaches the end, when the attractive power rapidly augments. If in the accompanying diagram A B be one half of a magnet, the curved line, *c d*, will represent the attractive force at different points, the distance of the line from the magnet indicating the relative degrees of attraction.

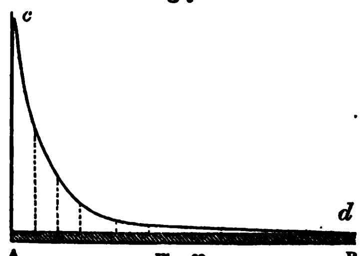


Fig. 69.

Further investigation into the phenomena of magnetism shows, that the force exerted at each end of a magnet possesses different properties. Thus, if there be two magnets, it will be found that two of the ends of the separate magnets will be forcibly attracted towards each other, whilst the opposite ends will be as strongly repelled. These mutually attracting and repelling properties may be readily shown by suspending a bar magnet by tying a waxed thread round its centre, and then bringing it near to one or the other end of a magnet laid on the table. It will be seen that the same end of the stationary magnet repels one end of the suspended magnet and attracts the other. It will be also seen that the end of the suspended magnet which is repelled will, when brought near the other end of the stationary magnet, be attracted. These opposite directions of the attractive force peculiar to each end constitute what is called the *polarity* of the magnet.

The concentration of the attractive power at each end of the magnetized bar, and the directions in which the two forces are exerted, are shown in a striking manner in the following experiment. Place a straight bar magnet on the table, and upon it lay a sheet of stiff pasteboard several inches longer than the

magnet, and steady the pasteboard at each end by resting it upon thin hooks. On sprinkling iron filings over the surface, they will be seen to arrange themselves in curves, as represented in the woodcut, fig. 70, the greater part of the filings being collected over each end of the magnet, and spreading out in curvilinear directions towards the two ends. Very few of the filings will collect on the spot over the centre of the magnet.

Fig. 70.

When this arrangement of the iron filings is closely examined, it will be found that each small particle of iron is endowed with magnetic power, and has a distinct polarity. The particles nearest to the poles of the magnet become separate magnets; they in their turn attract other particles, which, in like manner, become magnetic by induction, and attract particles more distant; and thus, by a continuous chain of minute magnets, the arrangement into lines is formed. But the magnetism thus induced from particle to particle becomes weaker and weaker as the distance from the original source of the power increases, as is evinced by the diminished number of the rows of filings. The peculiar curves in which the magnetized particles arrange themselves are attributable to the attraction excited by those parts of the magnet more distant from the two poles.

Several kinds of apparatus have been contrived to illustrate in a pleasing manner the mutually attractive and repulsive powers of the two poles. One of the simplest and most amusing of these contrivances is the magnetic swan. The figure of a swan may be cut out of pasteboard, and stuck into a flat piece of cork, to enable it to float upright on water. A small magnetized needle is then introduced into the cork or is run through the pasteboard. When the swan is placed in a large basin or a dish filled with water, it may be made obedient to the will of a person who presents towards it alternately one and the other end of a magnet. If the magnet be concealed in the coat sleeve, and a piece of bread be held in the hand, the movements of the swan seem more surprising.

The induction of magnetism in soft iron on the approach of a magnet bears a close analogy to the induction of electricity in insulated conductors on the approach of an excited electric. In the former case, as in the latter, the effect is produced without contact; and as an electric excited with one kind of electricity *induces the opposite* electrical state in the conductors near it, so

also the peculiar condition of one pole of a magnet induces the opposite condition of magnetism in the nearest part of soft iron. As an illustration of the peculiar properties of magnetic induction, place three or four nails on the table at short distances apart, and bring one pole of a magnet near to the head of the outermost nail, as shown in fig. 71. By this arrangement, the end N of the magnet will induce magnetism in the nail *b*, that nail will induce magnetism in *c*, *c* in *d*, and *d* will induce magnetism in *e*; the magnetism of each one, however, being less as its distance from the source of power increases.

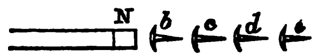


Fig. 71.

The induced magnetism continues only so long as the coercing force is excited, and the instant the magnet is withdrawn the nails lose their attractive power. It will be observed, also, that each nail while under the influence of the magnet possesses opposite poles; the magnetism induced in the head of the nail *b* will be of the opposite kind to that of the end of the magnet presented to it, whilst the magnetism at the point of the nail will be similar to that of the magnet. In the same manner, each of the nails will be endowed with the two kinds of magnetism, the heads and the points being differently magnetic. To prove that this is the case it will be only necessary to magnetize a sewing-needle by drawing it a few times from the eye to the point against the end of the magnet, and then, suspending it by a fine thread, to bring it successively near to the head and the point of each nail. It will be perceived that the point of the suspended needle will be repelled by the points and attracted by the heads of the nails.

The induction of magnetism in iron, and the resemblance of the phenomena to those of the induction of electricity, are clearly shown by the following experiment. Suspend two wires by fine threads, and bring a magnet towards their lower ends. The approach of the magnet will induce magnetism in the wires, and the poles of the two ends being endowed with the same kind of magnetism, the wires will mutually repel each other, as shown in fig. 72. The divergency will increase to a certain point as the magnet approaches, because the induced magnetism becomes stronger, but when the magnet is brought still nearer, its inferior direct attractive power will overcome the repulsion of the induced magnetism, and will draw the two lower ends towards it, in the manner shown in fig. 73.

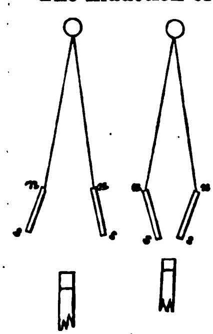


Fig. 72. Fig. 73.

The two other ends will still continue to repel each other, for, being farther from the attractive power, it is not sufficient to overcome the influence of the induced magnetism.

If whilst the two wires are divergent, as in fig. 72, the opposite pole of another magnet be brought above them, they will gradually collapse as the second magnet approaches until the magnetism induced by the first magnet appears to be entirely neutralized, and the two wires will lie together as if they were entirely uninfluenced by the presence of the magnets. The cause of this collapse of the wires on the approach of the second magnet is owing to the induction of opposite poles in the two previously magnetized wires, by which means the magnetic power in each is neutralized. That the power continues in the wire is evident on withdrawing either of the magnets, for then the wires will repel each other as before. The action of the suspended wires during these experiments closely resembles that of suspended insulated pith balls under the influence of induced electricity,* the balls being made to diverge on the approach of an excited glass tube and to collapse when an excited stick of sealing wax is brought near. In the case of magnetic induction, however, the effect of polarity is more distinctly marked, and it is essential that the inducing magnets should be brought near the ends of the wires.

The following experiment illustrates in a striking manner the neutralization of the magnetic force by a second magnet. Procure a piece of iron with two branches at one end, fig. 74. When the magnet N is applied to one branch, the iron becomes instantly magnetic; the end to which it is applied having an opposite state of magnetism induced in it to that of the opposite end E. The magnetism thus induced in the iron will be sufficient to enable it to support a key or a nail. But if, whilst the nail is suspended, another magnet be applied to the second branch S, with the opposite pole to that of the magnet N, the attractive powers of the magnetism communicated to the iron will be neutralized, and the nail will drop off. This experiment may be performed with a strip of ordinary tinned iron—commonly called sheet tin—which may be readily cut with an old pair of scissors into the required shape. In experiments with induced magnetism soft iron is much to be preferred to steel, for, in the first place, the magnetic force is more quickly

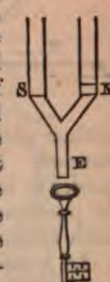


Fig. 74.

* See page 66.

imparted to iron than to steel, and it also more quickly disappears when the magnet is withdrawn.

There are several methods of imparting permanent magnetism to steel. When a magnet of small power is required, it is sufficient to rub a magnet from end to end of a steel bar several times, always beginning and leaving off at the same end and with the same pole of the magnet. Thus if a steel bar be laid on the table and one of the poles of a magnet be applied at one end and drawn to the other, the first operation will be sufficient to give a certain degree of magnetism to the steel. By repeating the operation a second time the magnetism will be increased, and after ten or twelve repetitions on both sides, the steel bar will become strongly magnetic. The magnetized bar may in the same manner be applied to impart magnetism to another without losing any of its power, and thus any number of magnets may be made from a single one. The magnetism imparted to steel bars will continue for years without diminution if they be kept in pairs ranged parallel to one another with the opposite poles connected together by pieces of iron.

When powerful magnets are required, a different process of communicating magnetism is adopted. The opposite ends of two strong magnets are applied to the centre of a thin steel bar, as shown in fig. 75, and are drawn towards each end. This operation is repeated several times on both sides of the bar until it has received its maximum quantity. Five or more thin bars of steel are thus treated, and they are then bound or rivetted together with the same poles united, so as to form a compound magnet. Magnets of this kind have been made of sufficient power to lift ten times their own weight. A compound magnet in possession of the Royal Society consists of 450 bar magnets, each fifteen inches long.

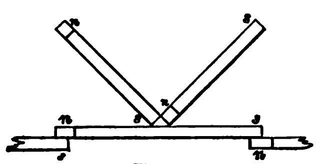


Fig. 75.

In communicating magnetism to steel by either of the two methods described, the magnetism at the end of the bar is of the opposite kind to that of the end of the touching magnet at the point where contact ceases. Thus in fig. 75, the end *n* being drawn from *n* to *s* of the bar of steel, the magnetism of the latter at *s* is of the opposite kind to *n*.

It might be supposed that in communicating magnetism by two magnets the centre of the bar where the two poles of the magnets are repeatedly applied would be magnetic, but if the

tion be properly performed the magnetism will be confined e two ends, and the centre will be neutral. This property larity is remarkably shown when a magnet is broken. In ase the central parts which previously exhibited no magnetic r become instantly endowed with magnetism of opposite , and each fragment of steel becomes a perfect magnet. same effect is produced however frequently the process of on and subdivision is carried on, so that a single magnet t be divided into a thousand, each one of which would two poles possessing different kinds of magnetism. In espect there is a remarkable difference between magnetism lectricity. When electricity is induced in a long insulated icting body, the two ends exhibit opposite kinds of elec-y; but if the conductor were divided in the middle and ated into two, whilst under the influence of the inducing ic, each of the two separated portions would be in different ical conditions.

e have hitherto considered the magnetic force to be greatest e extremity of the magnetized bar, and practically that is ase, for it is at the end that the greatest amount of lifting r can be obtained; but in point of the poles of a magnetized bar of are situated at a short distance from xtremity. This may be proved by ig a thin iron wire along the under e of a magnet suspended horizon- as shown in fig. 76. Let the mag- s be rested on the end of a book l upright. A piece of iron wire, *a*, at one end, to suspend a small scale-an then be moved along the mag- nd it will be found that the weight i support will be greater about one- of an inch from the end than at the mity.

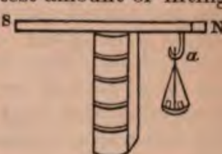


Fig. 76.

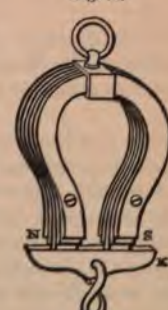


Fig. 77.

at possesses powerful influence on etic bodies. A strong steel magnet be entirely deprived of its power by ig it red hot, if its poles be left un-cted. The magnetic condition of when under the influence of heat , indeed, to be similar to that of soft iron. Magnetism is much more quickly induced than when it is cold, but it does etain the *power* when the inducing magnet is withdrawn.

If, however, the opposite poles of two magnets be applied to the ends of a heated bar of steel, and they remain there till it is cooled, the bar will be rendered strongly and permanently magnetic.

When great lifting power is required, the form of a horse shoe is given to the magnet, as represented in fig. 77. The two poles, N, S, are thus brought to act together as a compound magnet, and their combined attractive forces may be exerted on a piece of soft iron, K, called the keeper. The piece of iron becomes immediately magnetic by induction, and its two poles react on the poles of the inducing magnet, and thus add to the force by which they are mutually attracted.

CHAPTER XV.

TERRESTRIAL MAGNETISM.

North and south poles of magnets — The mariner's compass — Deviations of the magnetic needle — The dipping needle — Magnetic poles of the earth — Diurnal variations of the needle — Cause of terrestrial magnetism — Magnetic storms — Directive force of terrestrial magnetism — Irregularity of the compass in iron ships — Diamagnetism — Theories of magnetism.

WHEN a straight magnet is balanced horizontally on its centre, it will, after oscillating for some time, place itself in a position with one of its poles pointing towards the north. If that pole be marked it will be observed constantly to assume the same position, and if the other end be brought towards the north, the constraining force will be no sooner removed than the marked end will turn round and place itself as before. The polarity of the magnet is observable in every part of the earth's surface; for whether it be in Europe or in America, in Iceland or at the Cape of Good Hope, the same end of the magnet invariably turns towards the north. That end has consequently been called the north pole of a magnet, and the opposite end is called the south pole.

This attracting of the same pole always towards the north must be produced by some power in the earth which possesses polar influence, and this power is naturally assumed to be magnetism.

The discovery of the polar attraction of the earth is the most useful contribution science ever made to the commerce of nations, and to the diffusion of civilization and knowledge. The fact that a suspended magnet always turns the same end towards the north pole of the globe no sooner became known than its application to navigation was suggested; and directed by this guide sailors soon learned to track their way in the darkest night, when far out of sight of land, with the certainty of steering in the right direction.

The mariner's compass consists of a magnetized needle delicately balanced on its centre by a fine point. A circular piece of card board is attached to the needle, on which card the "*points of the compass*" *are marked*, the circle being divided into thirty-

two. A rectangular cross marked N. S. E. W., at the points north, south, east, and west, forms what are called the four cardinal points of the compass. The spaces between these are equally divided into four other points, distinguished as north-east, north-west, &c.; these again are equally subdivided into the points distinguished as north-north-east, east-north-east, &c., and a further subdivision completes the thirty-two points of the compass; the last points being distinguished by the preposition "by" before the last word, as north by east, east-north-east by east. The principal difference between a mariner's compass and an ordinary one consists in the method of mounting it between two concentric brass rings with independent bearings for the purpose of maintaining the instrument in a horizontal position during the heaving of the ship. The north pole of the compass does not point exactly to the north in this part of the world, but it is directed about twenty-two degrees to the west of the geographical meridian.

The deviations of the magnetic needle vary in different parts of the world, and are more or less considerable at different periods. At the present time, the amount of deviation in London is 22° west. When first observed, in 1576, it deviated 11° 15′ to the *east;* in 1657, the needle pointed directly to the north, from which date it gradually deviated to the west till 1815, when it attained its maximum of 24° 17′ 18″; and it has since been gradually, though slowly, veering easterly. This deviation from the true direction is called the *declination* of the magnetic needle. At Paris it was 11° 30′ to the east in 1580; the needle pointed to the north in 1663; the deviation was 8° to the west in 1700; 20° in 1785; and 22° 14′ in 1814. From that period its westerly tendency commenced to diminish, and in 1849 it was 20° 34′, or two degrees less than in London. The greatest variations that have been observed amounted to 43° 6′ east, in 60° of south latitude, and 93° east longitude; in Greenland the declination has been observed to extend 45° west of the geographical meridian.

The magnetism of the earth is indicated by another action on the magnetic needle besides its attraction to the north. It might have been assumed that if the source of magnetism were in the earth, and situated towards the north pole, the attractive force would be exerted, not only in drawing one of the ends of the magnet horizontally northwards, but that it would draw it also downwards, towards the magnetic pole of the globe. This is found to be the fact; for if a bar of steel be balanced horizontally and afterwards magnetized, the equilibrium is no longer *preserved,* and the north pole is attracted downwards towards

the earth. This natural inclination of the magnet is called its *dip*. The degree of inclination varies even more than the declination of the magnetic needle. Near the equator there is little perceptible dip, the attractions of the two poles being there nearly equally balanced; but on approaching the poles, the dip commences and goes on increasing the farther we advance north. At two points within the arctic circle the north pole of the dipping needle assumes a perpendicular position, as if the source of attraction were directly beneath. These points are called the magnetic poles of the globe. They are situated at considerable distances from the poles of the earth's axis. One magnetic pole was discovered by Sir John Ross to be situated 70° 5′ 17″ north latitude, and 96° 45′ 48″ west longitude, the dip being at that point within one minute of vertical. The other magnetic pole is in Siberia, in 102° east longitude, and in latitude north of 60°. The two magnetic poles are about 200 miles apart, measured across Greenland and Norway. One of the south magnetic poles is supposed to be near Cape Horn, and the other to the south of Australia.

The degree of the dip, as well as the amount of deviation, varies at the same place at different periods, though the variation of the dip is not to the same extent. In 1720, the dip of the needle in London was 74° 42′; in 1800, it was 70° 35′; in 1830, it was 69° 38′; and at the present time it is 67° 30′. In Paris, the observed inclination of the needle in 1671 was 75°; in 1791 it was 70° 52′; and in 1829 it was 67° 41′. The difference between the dip of the needle in the two latitudes of Paris and London, it will be observed, is about two degrees.

In addition to the variations in the declination and in the dip of the needle, which occur at intervals of years asunder in regular gradation, there are also more minute variations observable in different parts of the same day. The diurnal variation commences early in the morning, at which time the magnetic needle points in a more easterly direction than its medium position. At seven o'clock the easterly movement ceases, and it tends towards the west until two o'clock. About that hour it again turns towards the east till the evening, and regains its normal point during the night.

The phenomena of terrestrial magnetism open a wide field for inquiry; and the subject was considered so important that a conference of those who had made magnetism their study was held at Cambridge in 1845, during the meeting in that University of the British Association for the Advancement of Science, and it was determined to undertake a series of combined *observations in different parts* of the world, for the purpose of

elucidating the causes of magnetic action. Magnetic observatories have been established, and observations with ingeniously constructed instruments continue to be made by day and night; but hitherto there has not been much light thrown on the mysterious actions of terrestrial magnetism.

According to the general opinion at present entertained on the subject, the magnetism of the earth is due to the influence of the sun's rays striking on different parts of the equatorial portion of the earth during the revolution of the globe on its axis. This opinion is confirmed by the known relations between heat and electricity, and by the known fact, which will be more fully developed in a subsequent chapter, that heat, electricity, and magnetism are convertible into each other. The causes of the variations in the deviation and inclination of the magnet, and of the existence of different magnetic poles, remain as yet undiscovered.

The variations in the magnetic needle that we have hitherto noticed are generally gradual or periodical in their changes; but there are other disturbances of an irregular kind that strongly affect the needle, and make it oscillate quickly, as if it were under the influence of a power that is rapidly shifting its position or degree of force. These disturbances, which when violent are called "magnetic storms," have not been satisfactorily accounted for. They have an undoubted reference to the electrical condition of the atmosphere, and in northern latitudes they have been observed to be most violent when the aurora borealis is more than usually active and brilliant.

The attractive force of terrestrial magnetism is very feeble. The slight directive force with which a magnetic needle is drawn towards the north pole is evident from the small amount of magnetic power required to cause a deviation from the polar direction. When a magnetic needle is delicately suspended, it will be sensible of the approach of a magnet at a distance of several feet, and will obey the artificial force at that distance in opposition to its natural tendency. The amount of directive force has been measured by Coulomb's torsion magnetometer, and has been ascertained to increase on approaching the poles, with the increase of the dip. Assuming the magnetic intensity at the equator, where the needle is horizontal, to be 1, on advancing northward till the dip is 24°, the magnetic intensity is 1·1; when the dip is 64°, the intensity is 1·3; and near the magnetic poles it amounts to 1·7.

In consequence of the small amount of force exerted by the magnetism of the earth, the magnetic needle is very liable to *variations* from local influences. This is a matter of great

importance in navigation, especially since the extensive introduction of iron ships; and several wrecks that have recently taken place have been attributed to the defective state of the ships' compasses, caused by the iron of which they were constructed. The mere attraction of the iron would not be sufficient to produce this effect; for the attraction of a large mass on the small needle would operate nearly equally on each pole, and thus counteract the tendency to deviate; but when the iron of the ship by any means becomes magnetic, it may produce a powerful influence on the compass, and thus be the cause of serious disasters. It is an ascertained fact that a bar of iron—a poker, for instance—if repeatedly struck whilst it is held in the magnetic meridian, becomes permanently magnetic; and the hammering of an iron ship during its construction, and the strains to which the plates of metal are liable in a rough sea, are, it has been supposed, sufficient to impart permanent magnetism to different portions of the ship.

Several methods have been recommended and tried for correcting the influence of local attractions on the compass, the principle of which depends on placing near the magnetized needle a mass of iron so adjusted as to counteract, by the more powerful proximate attraction of the surrounding mass, the more remote, and consequently less powerful, attractions of masses of iron in different parts of the ship.

It was until recently generally supposed that the only substances in nature capable of becoming magnetic were iron and its combinations, and the metals nickel and cobalt. The slight indications of magnetism in other bodies were attributed to the presence of minute portions of iron, and it has been experimentally determined that a quantity of iron so minute as to be inappreciable by chemical analysis is capable of being acted on by a magnet. A new class of magnetic bodies has, however, been discovered, which are acted on the reverse way of their lengths, the polarity being in the direction of their shortest diameters instead of their longest. Professor Faraday, the discoverer of this peculiar property, has pursued the inquiry with his usual zeal and skill; and from the result of his researches it appears that all bodies which are not magnetic in the common sense of the term possess this remarkable property, which he calls diamagnetism. He ascertained that all such substances, when suspended between the poles of powerful magnets, place themselves in a position at right angles to the poles. The metal bismuth is the substance most powerfully diamagnetic, and stands at the head of the class, as iron is at the head of the magnetic bodies.

In the course of Faraday's experiments he operated, not only on solids and liquids, but on gases, which were also found to exhibit the property of polarity and diamagnetism when placed in what is called the "magnetic field"—that is, in the space included between the opposite poles of a powerful horse-shoe magnet. The different gases exhibited the property in various degrees, oxygen being the most strongly diamagnetic. The new field thus opened to investigation has been yet but imperfectly explored; and it seems not improbable that further researches will prove that the dissimilarity between magnetic and diamagnetic bodies is rather in the mode of manifestation than in the character of the force.

When the cause of the limitation of the power of magnetism to three of the known metals is discovered, we shall probably be enabled to perceive why the polarity of other bodies differs in its direction. Recent experiments, indeed, indicate that the difference of magnetism and diamagnetism is caused by the arrangement of the particles of matter, and that when the natural order is forcibly changed the magnetic character is also altered. When, for example, a short bar of bismuth is forcibly compressed in a vice, it loses its diamagnetic character, and if then placed in the magnetic field its two ends are attracted to the poles of the magnet in the same manner as a bar of steel.

It is the opinion of Faraday that all metals are magnetic, in the same way as iron, at certain extremely low temperatures. His experiments, however, to establish this opinion were not successful. At temperatures of 60° below zero, none of the other metals exhibited magnetic properties. Iron loses that property when heated to orange-red. A steel magnet loses its polarity at a much lower temperature, but the steel continues to be acted on by another magnet until heated to a bright red.

Various theories have been propounded to account for the phenomena of magnetism, but none are sufficiently satisfactory to be recognized as established. It is a prevailing notion that magnetic currents are actively circulating round the poles of a magnet, but such a notion is little better than a fanciful supposition. The fact—which we shall have to notice in the next chapter—that currents of electricity when circulating round a bar of iron renders it strongly magnetic, gives seeming countenance to the supposition; but we are at a loss to conceive by what possible means such currents could be excited and directed for years together round a bar of steel.

It is contrary to our present purpose to enter more fully into the examination of the many curious phenomena of magnetism. *Our principal* object in adverting to the subject has been to

explain the general and peculiar actions of a force so closely allied to electricity that we could not proceed farther with the consideration of the voltaic action without noticing its development. The mutual excitement of magnetism by electricity and of electricity by magnetism, which we shall shortly have to consider, exhibit such an intimate relation between the two that they can only be regarded as different modifications of the same force.

CHAPTER XVI.

ELECTRO-MAGNETISM.

Effect of voltaic currents on magnetic needles—Magnetism induced in the conducting wire—Directions of deflected magnetic needle by opposite currents—Multiplication of effect by coils of wire—Galvanometers, their extreme sensitiveness—Magnetic action of copper wires—Polar direction of a wire coil—Electro-magnets—Their great power and limited spheres of attraction—Ratio of diminution of attractive force—Proportionate sizes of wire and iron—Economical effect of long coils.

A CURRENT of electricity transmitted by wires from one end of a voltaic battery to the other meets with great resistance, even when passing through the metals that are the best conductors. The amount of this resistance is proportioned to the square of the diameter; and it increases rapidly, in some ratio not exactly ascertained, with the length of the conducting wire. The action and reaction that are thus continually in operation during the passing of a voltaic current produce remarkable magnetic effects, which extend to a considerable distance beyond the surfaces of the conductors.

The influence of frictional electricity in magnetizing and demagnetizing steel needles was known to Franklin and other of the early electricians; but it was reserved for Professor Œrsted of Copenhagen to discover, in 1819, the much greater magnetizing influence of a current of voltaic electricity. He discovered also that that influence is exerted not only by transmitting the current directly through the bar to be magnetized, but by a secondary action in other wires.

If a thick copper wire *c z*, connected with the opposite poles of a voltaic battery, be placed over a magnetic needle N S, balanced on its centre like the needle of a compass, and in the line of the magnetic meridian, the needle

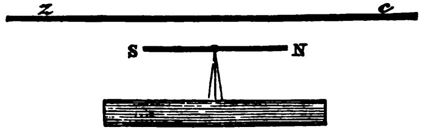


Fig. 78.

will be deflected the instant that the current passes through the wire; and it will remain deflected from its natural position in a

greater or less degree according to the strength of the current. If the current from the copper, or positive, pole of the battery pass from the north to the south pole of the magnetic needle, the deflection will be towards the east; but if the current pass in the opposite direction, the deflection of the needle will be towards the west. If the wire be then placed below the needle, the action will be reversed: the north pole of the needle, which was deflected to the west when the wire was above it, will be deflected to the east. A similar reversal of the deflections of the needle occurs when the direction of the electric current is changed by reversing the connections of the wires.

The conducting wire seems, in these circumstances, to be endued with polarity at right angles to its axis, as if an infinite number of small magnets were ranged tangentially to the wire side by side transversely to the direction of the current. The transmission of the electric current, indeed, appears to convert the conducting wire into a compound cylindrical magnet.

It is not essential that the conductor should be metal. Charcoal, and even acids, will, when conducting a current of electricity, become temporary magnets, and deflect the magnetic needle when it is placed parallel to the flow of electricity. The same power is exerted by the battery itself; for if a long magnetic needle be suspended from its centre over the cells ot a voltaic arrangement, it will be deflected in the same manner as a needle balanced over a conducting wire.

As the needle is deflected in opposite directions when the wire is placed above and when it is below, it appears, on the first view, as if the magnetic influence were changed by the alteration of position; but the change is only apparent and not real. Let c z, c' z' represent the conducting wire, with the current passing in the direction of the arrows from c to z. The magnetic needle *n s* is balanced on a pivot fixed to the wire, so that it may be turned round with it; and being held in a vertical position, and a trifle heavier at one end, it will not be affected by terrestrial magnetism. The wire on the left in the figure shows the north pole

Fig. 79.

of the needle deflected towards the right hand. Turn the wire *gradually round until* it is brought into the other po

then the north pole of the needle seems to be deflected in the contrary direction, though in relation to the wire it has remained unchanged; the apparent difference being caused entirely by its being seen from the opposite side.

Bend the conducting wire Z C into the form of a rectangle, and place a balanced magnetic needle in the centre of it, as in fig. 80; the end C of the wire being connected with the positive pole of the battery, and the end Z with the negative, or zinc end. The effect of this arrangement on the needle will be, in the first place, to deflect N towards the east by the influence of the current from C passing over the needle from north to south. The same current, if it were to return *over* the needle from S to N, would neutralise its first influence by the change of direction, and would bring the needle back to its original position. But by passing *under* it, the direction of the current in reference to the needle is reversed, and the influence is exerted to increase the first deflection towards the east, and the force of the current is thus doubled. By bending the wire again in the same manner an additional effect is produced; and by numerous reduplications of this kind the influence of the current may be so multiplied, that the needle

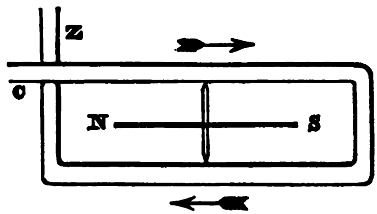


Fig. 80.

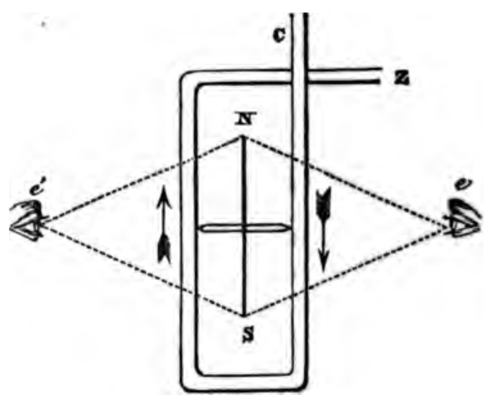


Fig. 81.

will be deflected by a quantity of electricity far too minute to *have any* sensible effect if passed over it through a single wire.

It will, perhaps, render this multiplied action of the voltaic current on the needle more clear if the same arrangement be placed vertically, as in fig. 81. The electric current from the positive pole of the battery passing from the north to the south pole of the needle, deflects it towards the right hand of a spectator placed in the position of *e*, and towards the left hand of a spectator at *e'*. The same current on its return towards z passes from the south to the north pole of the needle; but as it passes on the opposite side, the return current tends further to deflect the needle in the same direction, and it continues to point to the right hand of the spectator at *e*, and to the left hand of the spectator at *e'*, instead of changing positions as it appears to do in fig. 80, when seen on opposite sides during the passing of a single current.

The instruments called galvanometers, employed for indicating the presence of a feeble electric current, are constructed on the foregoing principle; and as each coil of wire that surrounds the needle seems to increase the effect, it might be supposed that the sensitiveness of such an instrument could be indefinitely extended. But there are limits to the length of the wire-coil, beyond which the sensitiveness of the needle is diminished instead of being increased. For instance, the influence of the conducting wire diminishes with its distance from the needle, and that distance becomes greater and greater with each additional superposed coil. With a view to increase the number of folds of wire as much as possible without lessening the effect by increased distance, very fine wire is used; which being carefully covered with silk or cotton, to prevent lateral conduction, may be wound on a rectangular bobbin close together, having a space in the middle for the introduction of the magnetic needle. In the galvanometers employed for the electric telegraph, it is customary to wind round the needle about 200 yards of covered wire as fine as a hair. But when such a length of very fine wire is used, the great resistance it offers to the passage of the electric current operates materially against the sensitiveness of the instrument, and currents of feeble intensity meet with so much obstruction, that the quantity which passes is scarcely appreciable; the otherwise augmenting effect of the reduplication of the wire being more than counterbalanced by the increased resistance.

As a magnetic needle when suspended horizontally, is attracted towards the north and south by the magnetism of the earth, it is necessary, when a horizontal single needle galvanometer is used, to place the coil in the magnetic meridian parallel to the needle. This is inconvenient in general experiments, and the sensibility of the instrument also is diminished by the directive influence of the earth, which tends to prevent the deflection

These defects may, however, be remedied by attaching to the vertical support a second magnetized needle above the coil, with its poles in a reversed position. By this means the directive tendency of the one is overcome by that of the other, and the needle remains in a neutral state in whatever position it may be placed. This contrivance, which was first applied by Professor Cumming of Cambridge, and afterwards improved upon by Chevalier Nobili, has given such increased sensitiveness to the galvanometer, that it indicates the presence of a very minute trace of a voltaic current.

Fig. 82 represents one of the approved forms of this kind of galvanometer, which has obtained the name of "astatic multi-

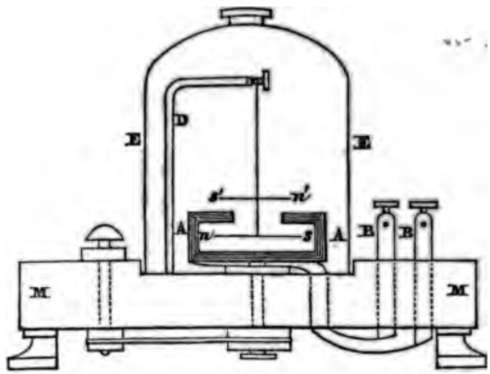


Fig. 82.

plier." A bent brass standard, D, screwed into the mahogany base, M M, serves as a support whence the magnetized needles, *n s*, *s' n'*, are suspended by a filamant of unspun silk, or by a human hair. The coil, A A, is formed of copper wire one-sixtieth of an inch in diameter, and two hundred feet long, carefully covered with silk.* The coil is made by folding the wire round a thin wooden frame, the top and bottom of which are about two inches square and half an inch apart. The ends of the wire pass through the base, and are soldered to the binding screws, B B. The needles are formed of pieces of thin watch-spring, straightened and strongly magnetized, or fine light sewing needles will answer the purpose. The needles are fixed to a light upright support, with their poles in opposite directions. One of the needles is within the coil, the other about a quarter

* *In some very delicate galvanometers the coil contains 800 yards of wire $\frac{1}{150}$th of an inch in diameter.*

of an inch above it. A circular piece of card divided into 360° is fixed on the top of the coil, the upper needle serving as the index to mark the degrees of deflection. There are screws, not marked in the diagram, for adjusting the card and the needles to their proper positions, and the instrument is covered with a glass shade, E E, to protect the needle from the influence of currents of air.

When it is required to examine the development of electricity, connections are made with the binding screws, B B, so that the current may pass through the coil and deflect the needle. The intensity of the current is generally estimated to be as the sine of the angle of deviation. This instrument is so extremely sensitive in its indications of an electric current, that if a drop of water be placed on the top of one of the brass binding screws, and it is touched with a zinc wire connected with the other binding screw, the needle will be deflected. This galvanometer is specially valuable in experiments with feeble currents of voltaic electricity, which are altogether inappreciable by the voltameter.

In the preceding illustrations of the magnetic properties of a wire conducting an electric current, the peculiarity of the phenomenon is, in some degree, masked by the intervention of the magnetic needle. Other experiments show more directly that the copper wire through which the current passes is for the time converted into a magnet.

Twist three feet of covered copper wire, about the thickness of bell-wire, round a pencil, so as to form, when the pencil is withdrawn, a hollow compact coil of wire, in form like a common bell-spring. Support the coil horizontally on a pivot, so that it may turn round freely, and let the wires at the ends dip into concentric cells of mercury, as represented in fig. 83, each cell being connected with one of the poles of a voltaic battery. The instant that the current is sent through the coil, it will begin to oscillate, and after a short time, will place itself in the magnetic meridian. If a magnet be brought near to either end of the coil, it will be attracted by one of the poles and be repelled by the other, exactly in the same manner as a steel magnet similarly poised. On reversing the connecting wires, so as to send the

Fig. 83.

current through the coil in the contrary direction, the magnetic *poles will be changed*, as will be indicated by the turning round

of the coil, the end that before pointed to the north being then directed towards the south.

The direction in which the wire of the coil is twisted also influences the position of the poles. When twisted from right to left, the current from the copper end of the battery will impart different polarity to that which a coil twisted from left to right possesses. That end of the coil at which the positive current is transmitted from left to right always points towards the north.

If the coil be doubled on itself by continuing to twist the wire in the same direction over the first single spiral, the magnetic properties will be considerably increased. By thus folding the coils of wire one over the other several times, powerful magnetic effects will be produced, and by adding to the number of the coils, the power will be increased, until the resistance offered to the current by the lengthened wire counteracts the multiplying tendency. The magnetism of such a coil is wonderfully augmented by introducing a bar of soft iron within it. The iron becomes in that case powerfully magnetic the instant that contact is made with the voltaic battery, and the magnetism of the iron, as well as of the coil, ceases almost as instantaneously when the electric circuit is broken.

The electro-magnet thus formed by surrounding a bar of soft iron with covered copper wire, owes its magnetic property entirely to the electric current that circulates round it. The iron seems to act as a conductor and concentrator of the force, and appears to bear nearly the same relation to the coil that the metallic coating does to the glass of a Leyden jar. It may be presumed that the same amount of magnetism is excited when the iron bar is withdrawn from the coil as when it is inserted; but without it the power is diffused through the wire, and is not concentrated so completely at the poles.

Iron possesses almost exclusively the peculiar property of thus conducting and concentrating the magnetic force. Even a steel bar produces scarcely any effect when introduced within the coil, unless the voltaic current proceeds from a combination of several pairs of plates; and when magnetism is thus imparted to steel, it does not disappear when the voltaic circuit is broken, but the steel bar becomes a permanent magnet. Why iron of all the metals should be thus peculiarly affected, and why the slight modification it undergoes in being converted into steel should produce such a change in its powers of receiving and retaining magnetism, are among the unsolved mysteries of science.

A bar of soft iron bent into the shape of a horse-shoe, and *then covered* with coils of copper wire twisted upon it in the

same direction, constitutes an electro-magnet of the most powerful kind. A straight and flat piece of soft iron, N S, sufficiently long to reach across the two ends of the bent bar, is attracted towards it with much more than double the force that a single bar magnet exerts.

Fig. 84.

The cause of the multiplication of the force by the application of a connecting bar of soft iron, which is called the "keeper" or "armature" of the magnet, has been explained in the foregoing chapter to be owing to the induction of magnetism in the iron; consequently, the attraction amounts not merely to that existing between a magnet and iron, but to the combined effects of two magnets acting on each other. For instance, that part of the keeper in connection with the north pole of the electro-magnet has southern polarity induced in it, and the opposite end becomes a north pole. Thus, during the time of contact, the keeper becomes a second magnet.

An electro-magnet of the horse-shoe shape, half an inch in diameter, and five inches long, with three or four spirals of covered wire, of the thickness of bell-wire, twisted round each limb in the same direction, and excited by only a single pair of plates, four inches square, will lift several pounds.

The magnetic power to be obtained by a current of electricity very far exceeds what can be permanently imparted to steel. An electro-magnet constructed by Mr. Joule was shown in the Great Exhibition, capable of lifting a ton weight; and electro-magnets of larger size have been made that lifted several tons. The most powerful permanent magnet in the Great Exhibition weighed 101 pounds, and lifted 436 pounds.

Though the attractive power of an electro-magnet is so enormous when the surfaces of the keeper and of the magnet are in close contact, the sphere of its influence is extremely limited. The thickness of a sheet of paper introduced between them will diminish *the power more* than one half, and at the distance of *half an inch apart* scarcely any attraction will be per

The influence of a permanent steel magnet extends considerably farther than that of an electro-magnet. The ratio in which the power decreases by distance has not, we believe, been determined; but there is good reason to suppose, that magnetism of both kinds obeys the same law as all central radiating forces, and that the diminution is proportioned to the square of the distance.

It may, indeed, appear at first sight irreconcileable with the observed difference in the extent of the influence of permanent and electro-magnets, that the ratios of decrease should be alike in each; but the seeming discrepancy vanishes if we suppose the centre of attractive power to be more deeply seated in the steel—which becomes permanently magnetic by some retentive power in its particles combined together as a whole—than in the soft iron, which acts only as a conductor of the magnetic force induced in the copper wire by the electric current.

Figure 85 represents one of the poles of a permanent bar magnet. Assuming the focus of attraction to be situated at C, a point equally distant from the sides of the bar and from the upper surface, then the lines B C, D C, drawn to that centre, will show by their radiation the ratio of decrease of the magnetic power by distance, in the same manner as, if C were the centre of an emanating force, they would indicate its proportionate diminution of energy. For example: let C be one quarter of an inch from the upper surface of the steel bar, and assume the attractive force at the surface to be equal to lift one pound. Then, if the force diminish according to the square of the distance, at a quarter of an inch from the surface, that is at twice the distance from the centre of force, the magnet would lift a quarter of a pound; at the distance of half an inch it would lift the ninth part of a pound; and at the distance of three quarters of an inch, that is, at four times the distance from the centre of attraction, it would lift one-sixteenth part of a pound.

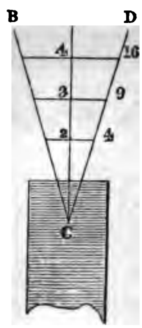


Fig. 85.

Fig. 86.

Let us next consider the effect of the diminution of force in an electro-magnet with a similar ratio of decrease. The centres of attraction are assumed to be on the surface, or, for the sake of calculation, one-hundredth part of an inch beneath it; the weight that the magnet will lift being one pound, as in the former case. Then, assuming the ratio of decrease to be

ame, at three times the distance from the surface that the ice itself is from any of the centres of attraction, the power be reduced as before to one ounce; but the measured dise will now be less than the thirty-third part of an inch, ad of three quarters, for the point whence the ratio of ease commences is nearly on the surface of the magnet. At distance of three quarters of an inch the power would be ced to less than the five-thousandth part of a pound.

'he intensity of electro-magnets, or the spheres of their ctions, increases with the intensity of the voltaic current, with the number of the coils of wire that surround them. s a bar of soft iron a quarter of an inch in diameter, covered numerous coils of fine wire, and excited by a battery of ve pairs of plates, will have a greater attractive distance a bar half an inch diameter, with a fewer number of of thick wire, and excited by a single pair of large plates, gh the latter magnet may sustain a heavier weight when surfaces are in contact.

a making an electro-magnet, regard should be had to the ive thicknesses of the iron and of the copper wire that is to the coil. Bell-wire, number 16 gauge, is suitable for bar half an inch in diameter. A rod about five inches long ld be bent into the form of a horse-shoe, having each limb qual length, and the two ends filed perfectly flat and even. ngth of 100 feet of wire, fully covered with cotton, d round both limbs in same direction, either right to left or left to t, will make a magnet ch, when excited by a ent from two pairs of es six inches square, will upwards of 20 pounds. onvenient plan of facili-ng the making of the coils o wind the wire on sepa- short lengths of brass e of sufficient diameter to it the iron which is in-ed after the coils have a separately made. By means the coils of wire be readily wound to any length that is desired. The dian represents the coils and iron detached from each other.

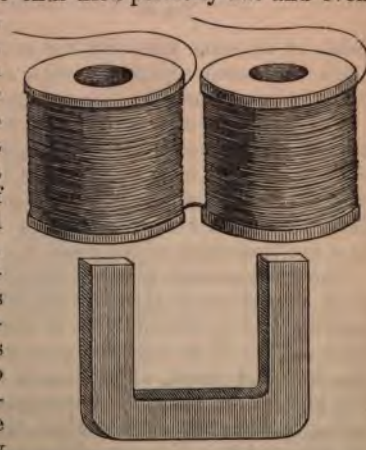


Fig. 87.

A shorter length of thick wire will produce a stronger attractive force than a long coil of thin wire, because though the multiplying effect of the reduplication of the coils is less, it allows a much larger quantity of electricity to pass. The use of the thick wire is, however, attended with a much greater loss of battery power. It is an object, in an economical point of view, to extend the length of the coil as far as practicable without diminution of magnetic force, for by that means an equal amount of power is gained with a feebler current; the reduplication of the wire compensating by its repeated efforts for the diminished quantity of electricity which will pass in a given time through the greater length of wire.

To illustrate the advantage gained by numerous coils of wire, let a voltaic current from several pairs of plates pass through two electro-magnets A, B, joined together in the same circuit; A being large and covered with a few coils of thick wire, and B a smaller magnet with numerous coils of fine wire. The magnetism of A will be extremely feeble at the same time that B is energetically attractive; though when connected separately with a voltaic battery of a single pair of plates, A may be the stronger magnet of the two.

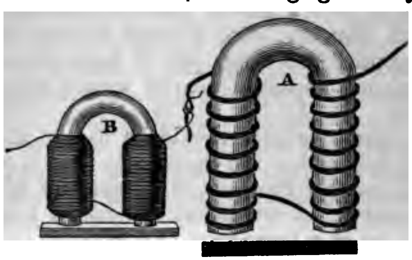


Fig. 88.

The greater consumption of zinc in the battery in imparting magnetism by short coils of thick wire is indicated by the rapid evolution of gas in the cells when the circuit is short, compared with the action when it is transmitted through a long circuit, though the latter may be capable of producing an equal effect by a multiplication of the coils.

The electro-magnets used for telegraphic purposes, in which great sensitiveness is required, with a current very small in quantity but of considerable intensity, are made of iron about three-eighths of an inch in diameter, coiled round with nearly two hundred yards of extremely fine wire covered with silk. The keepers of these electro-magnets are attached to a slender spring to force them back when the circuit is broken, and they are adjusted to a distance of not more than the tenth of an inch from the magnet. These electro-magnets work briskly through a circuit of upwards of 400 miles, with a battery consisting of *100 pairs of plates.*

CHAPTER XVII.

ELECTRO-MAGNETISM CONTINUED.

Rapidity of electro-magnetic action—Residual power in electro-magnets—Secondary currents by electro-magnetic induction—Medical coil machine—Ruhmkorff's coil apparatus; its beautiful exhibition of intensity electricity—Peculiar heating effects of the inductive coil—Mr. Hearder's improved coil—Rotary motion of conducting wires by tangential action.

THE rapidity with which magnetism is imparted to soft iron on making contact with a voltaic battery, appears to be simultaneous with the transmission of the electric current. If there be any retardation in the effect, it is to be attributed to the resistance of the molecules of iron to receive the magnetic property from the transmitting wire; for magnetism is manifested in the wire the instant that the voltaic circuit is completed. An apparatus represented in the annexed diagram is admirably calculated to show the extreme rapidity of electro-magnetic action. A short bar electro-magnet A is mounted on a wooden stand B. A piece of brass is fixed to the top, which serves for the attachment of a small keeper K to the magnet, and for the support of a bent brass arm C, used for the purpose of applying an adjusting screw S. The keeper is attached to a slender spring, which forces it

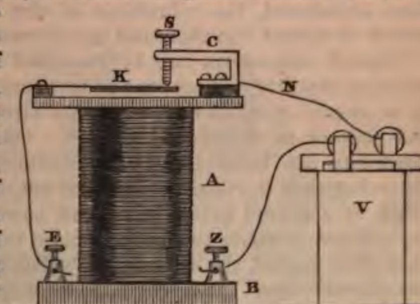


Fig. 89.

from the magnet against the screw when the voltaic current is not passing. One of the poles of the battery V is connected directly with the lower end of the coil-wire by the binding screw Z, and the other wire N is connected with the screw S, against which the keeper presses. The arm C is insulated from the brass to which the keeper is fixed by being screwed into a piece of boxwood, and the other end of the coil of wire is connected

by the binding screw E with the keeper. By this arrangement the electric circuit is completed through the coil, by passing through the bent arm and through the keeper. The points of contact should have small pieces of platinum soldered to them to prevent corrosion of the metal, which would otherwise soon stop the action.

The instant that the keeper is attracted towards the magnet, its contact with the screw is broken, and the voltaic current is interrupted. The magnet then ceases to act, the keeper is forced against the screw by the spring, and the contact being again renewed, the electro-magnet is brought into action as before, but to be again instantaneously demagnetized by attracting the keeper. It will be observed, therefore, that the circuit is broken every time that the keeper is attracted by the magnet, and renewed when forced back against the screw; and that each movement of the keeper indicates that the iron has been magnetized and demagnetized. When the voltaic battery is put in action, the keeper of the electro-magnet is attracted and forced back again with a rapidity altogether incalculable by the eye, the vibrations being so rapid as to produce a humming sound, which is more grave and acute according to its rapidity. By turning the screw S, so as to bring the keeper more close to the electro-magnet, the rapidity of the vibrations increases with the increased attraction of the magnet; and by the musical note thus occasioned, the vibrations of the keeper have been estimated to exceed one thousand in a second.

Though magnetism can be imparted and removed with this amazing rapidity, the amount of magnetic power is in such cases by no means equal to that which the electro-magnet exerts when the contact is of longer duration. Only a given quantity of electricity can be excited by the battery in a given time; and assuming that it requires chemical action to be continued one-tenth of a second to obtain the full power of the battery, when the contact is made and broken more frequently than the tenth part of a second, the quantity of electricity that passes is very considerably less. It appears, indeed, from the result of numerous experiments on this subject made by the author, that the full effect of an electro-magnet, with a coil of thirty yards of thick wire cannot be obtained more frequently than four times in a second.

When the keeper of a horse-shoe electro-magnet is in contact with the two poles, some magnetic power is retained after the contact is broken; and to prevent the continuance of the induced magnetism it is requisite to interpose a piece of card or thin leather, so that the keeper and the magnet may not touch each other. Besides this retention of magnetism by the keeper,

the electro-magnet itself retains its power for a short time, if the bar of soft iron be above three or four inches long; therefore, to insure rapid action, it is desirable that the iron round which the wire is coiled should be as short as possible.

The effect of secondary currents of electricity was soon found to be greatly augmented by the aid of electro-magnets. The introduction of a bar of soft iron within the coil of the wire, through which the electric current was transmitted, was found to increase in a marvellous manner the force of the shock induced in the second coil of fine wire wound round it. The effect was still further increased by introducing within the coil a bundle of fine iron wires instead of the solid bar. The magnetic attraction of the iron bar also facilitated the means of making and breaking contact with the battery. The self-acting method of breaking contact represented in fig. 89, has been applied with great advantage for that purpose, and a very useful apparatus for medical purposes has been constructed on this principle. In the accompanying woodcut the horizontal cylinder represents the coils of wire; the inner one being as thick as bell-wire, and twenty yards long, and the outer coil consisting of several hundred yards of fine covered wire. The inner and thicker wire is twisted round a hollow core into which the

Fig. 90.

bundle of iron wires can be introduced. The contact-breaker is sometimes applied at one end of the coil, and each time that contact is broken, a secondary current is induced through the fine wire. In *the form of* the apparatus shown above there is a *separate small electro*-magnet introduced for the purpose of

breaking contact. Brass handles are soldered to the ends of the second wire to increase the surface contact when grasped by the hands, or conducting-plates are used when the electricity is transmitted through other parts of the body. The making and breaking contact by the self-acting vibrations of the keeper, produce a rapid succession of shocks, the strength and rapidity of which may be regulated by the adjusting screw.

The strength of the shock given by an apparatus of this kind with a Smee's battery of only a pair of small plates, is stronger than most persons would like to receive. To regulate the strength of the shock, several means have been contrived. The withdrawal of the bundle of wires from the inner coil greatly diminishes the effect. This method is generally adopted for regulating the shock, and the difference occasioned by the presence of the wires on the electricity induced, affords a good illustration of the influence of magnetism in producing the effect. In the medical coil apparatus, as sometimes made, a small tube containing water is interposed in the secondary current, and the strength of the shock is regulated by a metal plunger which increases or diminishes the water space through which the induced current has to pass.

A more powerful apparatus of this kind, in which greater attention is paid to insulation, has been constructed by M. Ruhmkorff of Paris, which exhibits the effects of induced electricity in a remarkable measure, and serves to identify completely the electricity excited in secondary currents by the voltaic battery with the electricity excited by friction.

Ruhmkorff's induction coil apparatus of the largest size consists of a primary coil fifteen inches long, containing about eighty yards of stout covered wire in 400 convolutions. This coil is covered with several folds of varnished silk to insulate it from the coil of fine wire in which the secondary current is excited. It has been found an improvement to increase the insulation by enclosing the primary coil in a glass tube. The fine wire used by M. Ruhmkorff is one-hundredth part of an inch in diameter, and he employs usually six thousand yards of it well covered with silk and varnished. The contact-breaker is of the kind shown in fig. 89, the points of contact being made of thick platinum. At the recommendation of M. Fizeau a large conducting surface, consisting of several square feet of tin foil pasted on each side of varnished silk, is connected with each of the wires through which the voltaic current is transmitted. By this means the effect is greatly increased, as a more powerful battery may be used without injury to the platinum surfaces of the contact-breaker.

When an apparatus of this kind ... connection with a

voltaic battery of three or four cells, torrents of electricity in a high state of intensity are evolved through the secondary wire. When the two ends of the wire are brought within the eighth of an inch together, a constant succession of bright sparks pass between them, and when placed under the receiver of an air pump, rapid discharges take place when the wires are five inches apart. The phenomena exhibited by an apparatus of this kind, when in an exhausted receiver, are among the most beautiful in the range of electrical experiments. The floods of purple light, accompanied by corruscations of light of different colours that stream from the ends of the secondary wires, are of the same character as, though much more brilliant than, the streams of light that pass through an exhausted tube when connected with the prime conductor of a powerful electrical machine.

The following is the account of an experiment with a Ruhmkorff's coil apparatus of the largest kind, as given by Mr. Gassiot:*—"I coated about two-thirds of the inside of a Berlin glass beaker of four inches deep by two inches wide with tin foil, leaving about 1·5 inch of the upper portion uncoated. On the plate of the air pump I placed a glass plate, and on it the glass beaker; covering the whole with an open-mouthed glass receiver, on which was placed a brass plate having a thick wire passing through collars of leather. The portion of this wire within the receiver was enclosed in an open glass tube. One end of the secondary coil was attached to the wire, and the other to the plate of the air pump. As the vacuum improves, the effect is truly surprising. At first a faint clear blue light appears to proceed from the lower part of the beaker to the plate. This gradually becomes brighter, till by slow degrees it rises, increasing in brilliancy, until it arrives at that part which is opposite, or on a line with, the inner coating; the whole being intensely illuminated. The discharge then commences from the inside of the beaker to the plate of the air pump in minute but diffused streams of blue light. Continuing the exhaustion, at last the discharge takes place in the form of a continuous stream, overlapping the vessel as if the electric fluid was itself a material body running over. When first witnessed it appears at the moment impossible to divest the mind of such a conclusion."

The curious fact was also remarked by Mr. Gassiot that when a continuous discharge of electricity is passing between the ends of the secondary coil, when brought within an eighth of an inch of each other under atmospheric pressure, the *negative* one becomes red hot, whilst the other remains cool, and on reversing

* *Philosophical Magazine*, vol. xliv., for 1854.

the poles of the battery, the wire which was before hot immediately cools, and the other wire, which is then negative, becomes red hot. This appearance of heat at the negative wire of a secondary current is, it will be observed, contrary to what occurs when a current directly transmitted from the voltaic battery, for in that case it is the positive wire that is heated, and the negative one that remains cool.

Great improvements have been made in the induction coil apparatus by Mr. Hearder of Plymouth. By careful insulation of the wires, he has obtained more powerful results than those from Ruhmkorff's coil, with considerably shorter lengths of wire. The length of the secondary wire of the largest of Ruhmkorff's apparatus is, we believe, ten miles; whilst that in Mr. Hearder's is less than three miles. We have been favoured by Mr. Hearder with the following account of some of the astonishing effects produced by this improved induction apparatus. It gives sparks between the terminals nearly three inches long in free air, with a battery of twelve nitric acid cells; and through the flame of alcohol the sparks are eight inches long. Each single terminal gives sparks sometimes more than an inch in length. *Both* terminals become white hot when brought about one-third of an inch from each other, and when composed of fine platinum wire both melt into globules; whilst with Ruhmkorff's machine the negative terminal alone becomes red hot. In an exhausted receiver three feet long, a splendid ribbon of light is produced, bright in the centre, and surrounded by a magnificent crimson light shading off into violet and purple. Mr. Hearder observes:—"I have a vast deal of new matter which is not yet prepared for publication, touching the real static condition of the terminals, and the character of the current; if, indeed, it is a current at all, as I can produce most extraordinary effects under circumstances which preclude the possibility of the transmission of any current whatever. The effects of the induction machine are the most complicated and perplexing that I have ever studied. I should mention that my battery is a modification of Grove's, only I use a saturated solution of muriate of ammonia instead of sulphuric acid for the zinc; this dispenses with amalgamation, and is in every respect equally powerful."

Reverting to the deflective action of a conducting wire on a magnetic needle, it will be observed that the action is a tangential one; that is, the direction of the force is at right angles to the diameter of the wire. One pole of the needle is deflected to the right hand, the other pole to the left hand; and on whatever side of the wire the needle is placed, the same effects take place. *Thus, if* the conducting wire were surrounded by a number of

magnetic needles ranged parallel to it, they would be all deflected in the same manner, evidently showing that the deflecting force acts tangentially at every point of the circumference of the wire. The tendency of this force acting tangentially on all parts of the circumference of the conducting wires in the same direction is to cause a rotation of the wire on its axis, and to communicate motion in the opposite direction to the magnets within its influence, by the force of reaction.

Faraday, who was the first to take this view of the character and tendency of the electro-magnetic force, succeeded in illustrating it most satisfactorily by experiment. To do this, it was necessary to remove the counteraction of one of the poles of the magnet on the other; for as the south pole of a magnet is deflected in the opposite direction to that of the north pole, the contrary forces, when allowed to operate, completely neutralize each other.

The simplest arrangement for producing the rotation of a magnet is that shown in fig. 91. Into the bottom of a wooden cup, A, made to contain mercury, is inserted a wire, *d*, to which a bar magnet is attached by a thread. When the cup is filled with mercury, the steel magnet being the lighter rises to the top, and is retained in an upright position by the thread. A thick wire, *c*, connected with the positive pole of a voltaic arrangement, dips into the mercury, but is insulated from it by being covered with gutta percha or varnished cotton, excepting at the end. When a voltaic current is transmitted through the conducting wire, it influences the north pole of the magnet, but after communicating with the mercury, it is so diffused that the south pole is not affected. By this means the tangential force with which the induced magnetism in the conducting wire acts on the north pole is not counteracted, and the magnet being free to move in a circular direction, begins to rotate round the conducting wire.

Fig. 91.

Fig. 92 shows another form of apparatus for illustrating this remarkable phenomenon. Two long but light magnets, N S, N′ S′, are fixed into a circular piece of wood, D, which rests on a pivot, B, so as to turn round easily. The conducting wire, *c*, from the copper end of the battery, dips into a cup of mercury in the wood, and by means of mercurial connection the electric current is conducted through the wire Z to the negative end, without passing near the southern poles of the magnets. The connection

with the battery being completed, the magnets rotate freely round the conducting wire in the direction from left to right, like the hands of a watch. On reversing the battery connections, so that the positive current may enter at z and return up

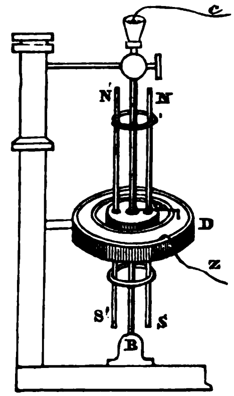


Fig. 92.

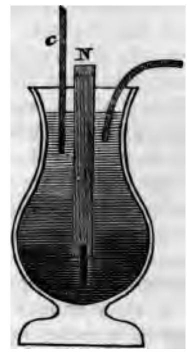


Fig. 93.

the wire to *c*, the direction of the rotation is changed. A similar change in the direction of the motion also occurs when the position of the poles of the magnets is reversed.

The rotation of a bar magnet on its own axis may be effected by an arrangement similar in principle to the foregoing. The contrivance originally proposed by M. Ampère is the simplest. The magnet, N (fig. 93), is allowed to float in mercury, being kept in a vertical position by a weight of platinum; and the action of the electric current is confined to one pole of the magnet by insulating the conducting wire, *c*, with the exception of its end, and introducing it vertically into the mercury to the depth of half the magnet. Another wire connected with the negative pole of the battery just dips into the mercury to complete the circuit. The counteraction that would otherwise occur [illegible] the other pole is thus prevented, and the magnet rotates [illegible] on its axis.

CHAPTER XVIII.

MAGNETO, THERMO, AND ANIMAL ELECTRICITY.

Induction of electricity by magnetism—Multiplication of effects by motion—Magneto-electric machines: their powerful effects—Magneto-electric spark—Decomposition by magneto-electricity—Correlation of magnetic and electric forces—Development of electricity by heat—List of thermo-electrics—Thermo-electric batteries—Indications of temperature by thermo-electricity—Animal electricity—Electrical organs of the torpedo—Identity of animal and voltaic electricity—Electrical power of the gymnotus—Connection between nervous influence and electricity.

THE intimate relation which subsists between electricity and magnetism as exemplified in the induction of magnetism by a voltaic current, is still further manifested by the induction of electricity by magnetism. It was, indeed, at once inferred that as all electric currents are accompanied by the excitation of magnetic properties, there would be a reciprocal excitation of electrical power by magnets. The verification of this inference is one among the many facts for which electric science is indebted to Dr. Faraday.

The simplest mode of inducing electricity by magnetic action is by an arrangement of permanent magnets and an electro-magnet, shown in the diagram.

Two long permanent bar magnets, N S, S N, are placed in the manner represented, with their opposite poles joined at one end

Fig. 94.

and spread out at the other; each of the separated poles being in contact with a bar electro-magnet, M, round which there is coiled about 200 feet of covered wire, the sixtieth part of an inch in diameter. The ends of the coil of wire are connected with a galvanometer, G, placed at such a distance from the magnets as to be beyond their direct influence on the magnetic needle. Whilst the magnets continue thus connected, the galva-

nometer will not indicate any trace of electricity; but the instant that contact is broken, a current of electricity is induced in the coil of wire, and the galvanometer is strongly deflected. The effect is, however, only instantaneous, and the needle, after a few vibrations, returns to its normal position. On making contact again, the galvanometer is again deflected; but the deflection is in the contrary direction to that on breaking contact. The electricity thus excited is in all respects like that of the secondary currents induced on making and breaking contact with a voltaic battery. The more suddenly contact is made and broken, by jerking away either of the magnets, the more powerfully is the galvanometer deflected.

The current of electricity induced by the arrangement shown in fig. 94, is very small in quantity, even when the most powerful magnets are employed; but the further researches of Faraday led to the discovery of new modes of action, by which the current may be prodigiously increased, and all the effects of a powerful voltaic battery, either of high intensity or of great quantity, may be produced by permanent magnets without any battery whatever.

Faraday was stimulated to his investigations on this subject by the remarkable phenomenon observed by M. Arago, of the induction of magnetism by motion in substances not otherwise magnetic. The French philosopher discovered, that if a copper disc be revolved close to a magnetic needle the needle is deflected. He also ascertained, that when a magnet is suspended, so that it may rotate in a plane parallel to that of the disc, when the disc revolves the magnet tends to follow its motion, or if the magnet be rotated the disc tends to follow it. The influence to motion in these cases is so strong, that magnets or discs of many pounds weight may be thus carried round. This effect, M. Arago stated, not only takes place with metals, but with all substances, solid or liquid, and even with gases. It must be observed, however, that in repeating these experiments, neither Mr. Babbage, Sir John Herschel, nor Dr. Faraday was able to produce the effect with any substances that were not very good conductors of electricity.

The experiments conducted by Faraday with the view of elucidating these phenomena, led him to the conclusion that whenever a metallic body is put in motion close to a magnet, a current of electricity is induced, which ceases the instant that the motion ceases. As the movement of any metallic body, such as a disc of copper, in close proximity to the poles of a permanent magnet was found to induce a temporary electric current in the metal, Faraday inferred that the effect would be increased if, instead of a

opper disc, a coil of covered copper wire round a bar of soft iron rere used. This was tried with most satisfactory results; and ther electricians have applied the principle to the construction f magneto-electric machines, that excite torrents of electricity y the rapid rotation, close to the poles of a powerful permanent lagnet, of a piece of soft iron surrounded by coils of covered opper wire.

Fig. 95 represents one of these magneto-electric machines. powerful compound permanent horse-shoe magnet *a* (composed f several thin plates of steel separately magnetized and bound ogether), is fixed in a horizontal position. The soft iron covered rith copper wire *c d*, by the rotation of which the electricity is nduced, resembles a horse-shoe electro-magnet; but instead of eing a bent bar of soft iron, it is made of two short straight bars onnected together by a cross piece of soft iron. This form is dopted because it facilitates the winding of the numerous coils f wire, and is more convenient for the mechanical arrangements. Vhen intensity effects are required to be produced, the iron of he rotating electro-magnet, called the armature, is of small iameter, and about fifteen hundred yards of very fine insulated rire are coiled round both limbs. When quantity effects are ranted, the armature is made of iron of greater diameter, and the oil is but one-tenth the length, and is of the thickness of bell-wire.

The armature is fixed on to a spindle attached to a small rooved wheel that is worked by a band over a larger wheel, by

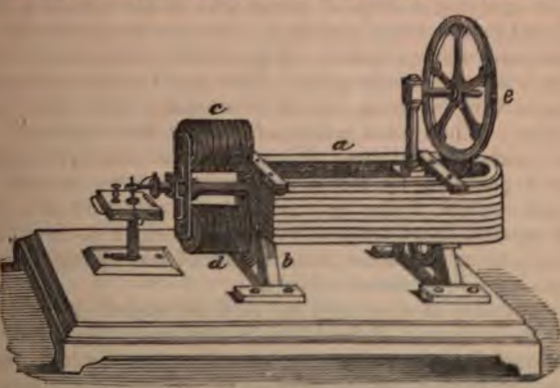


Fig. 95.

hich means very rapid motion may be given to it. Wires, rough which the induced electricity is conducted, are connected ith each end of the coil of wire round the armature; and as the

latter revolves as closely as possible to, without actually touching the poles of the magnet, alternate currents of negative and positive electricity are transmitted. Arrangements are made, either by projecting points dipping into mercury, or by springs pressing on interrupted collars of metal, for breaking the circuit of the wire coil the instant that the two ends of the armature come opposite the poles of the magnet; by which means the rotating electro-magnet becomes magnetized and demagnetized twice in every revolution, and at each break in the circuit a current of induced electricity is transmitted through the coil.

When the armature with the long coil of fine wire is used, a succession of very severe shocks may be received, on communication being made between the wires by grasping two conducting metal cylinders. The decomposition of water, and of all compound bodies that are decomposable by voltaic electricity, may also be effected, and a rapid current of most brilliant sparks is emitted at the points when contact is broken. With the armature of thicker and shorter wire, the metals may be ignited, and all such effects can be produced as may be obtained from a voltaic combination of a few large-sized plates. The sparks, on breaking contact, are also brighter, but no shock is given by the quantity armature.

Good contact is essential to the success of all experiments in electro-magnetism, and to insure it, it is customary to amalgamate the connecting points with mercury, which may be readily done by applying a drop of nitric acid to the terminal copper wires, and then rubbing a globule of the mercury over the part. This is particularly requisite when mercury is employed in connection with one of the poles. The liquid metal is, however, apt to be thrown about, and it is attended with other inconveniences. When solid points of contact are employed, they should consist of platinum. With the other metals, the ignition of small particles by the secondary current on making and breaking contact, forms an oxide of the metal on the points, which, after a short time, interrupts the electric circuit; but platinum, being the most incorrodible of the metals, is not so liable to have its surfaces oxidized.

The quantity of electricity induced by magnetism is proportionate to the power of the magnets employed. In a very large and powerful magneto-electrical machine constructed by Mr. Clarke, the *magnet battery* consists of 106 cast steel bars, each four feet long, and when combined, weighs 156 pounds. With this machine, a cubic inch of gas from the decomposition of water is evolved in one minute and a-half, the shocks are too *powerful to* be received without danger, and the sparks, when

the quantity armature is used, are accompanied with a loud snapping noise like the discharge of a Leyden jar.

The induction of electricity by magnetism alone seems to open an exhaustless source for the supply of electric force without the trouble, the annoyance, and the cost of voltaic batteries; but hitherto it has not been of much avail. The labour of turning the wheel for the rapid rotation of the armatures, and the irregularity in the force consequent on irregularity of mechanical action, are serious drawbacks to the use of magneto-electric machines as the generators of electricity for experimental purposes. As an economical means of exciting electricity for electro-plating, it was at one time thought to promise great advantage. A patent was obtained for the application of magneto-electricity to that purpose, and Messrs. Elkington constructed at their works in Birmingham a very large machine to be worked by steam power; but it was not found to answer so well as voltaic electricity, in consequence of the want of continuity and steadiness in the electric current produced. Magneto-electricity has also been applied by Mr. Henley to work a needle telegraph with very good effect, as will be subsequently noticed.

The mutual transmutation of the two forces into one another proves, in the strongest possible manner, the intimate connection, if not the identity, of electricity and magnetism, though manifested in so many different ways. This peculiar transmutable force is seen at one moment exerting limited though energetic attractions on steel and iron alone; at another, it is operating on compound substances of every kind, separating their elements from the most intimate combinations; again, we see it emitting light that rivals the sun in brightness; now it is carrying lightning-messages through hundreds of miles of wire, rather than force its way through a gossamer web; and yet, again, we see the same force dealing destruction in its course, as it rends a passage through the air from the clouds to the earth.

The development of heat being a characteristic phenomenon of an electric current, it was inferred that heat was also capable of developing electricity. The satisfactory proof of this inference is due to Professor Seebeck, of Berlin; and though this interesting branch of electric science has yet made no important progress, sufficient has been done to prove that heat, electricity, and magnetism, are correlative forces.

All that is necessary for the development of thermo-electricity is to heat any metallic body irregularly at its extremities. The *thermo-electric relations* of metals have not, as at present ascertained, *any connection* with their relative voltaic or con

properties. In the following list the combination of the metals at the two extremes produces the strongest electrical effects, the effect of the intermediate metals in the series diminishing as they approach. Those at the top of the list, commencing with galena, are positive to all below.

1. Galena.	6. Tin.	12. Zinc.
2. Bismuth.	7. Lead.	13. Iron.
3. Mercury.	8. Brass.	14. Arsenic.
4. Platinum.	9. Gold.	15. Antimony.
5. Manganese.	10. Copper.	
	11. Silver.	

The arrangement shown in the annexed diagram represents a simple thermo-electric circuit that exhibits the phenomena in a very satisfactory manner. The rectangle B D represents a frame of metal; the rectangular bar B C D being of bismuth, soldered at the corners B and D to a similar rectangular bar of antimony. A magnetic needle M is poised in the centre, and the whole is supported on an elevating stand. On applying heat to either of the corners B or D the magnetic needle is immediately deflected, thus indicating that an electric current is passing through the bars. The quantity of electricity excited is, to a certain point, proportionate to the different degrees of temperature communicated to different parts of the same metallic bar, and does not depend on the absolute heat. Thus the application of ice will produce an electric current as well as the application of heat; and by applying ice to one corner and the flame of a spirit-lamp to the other at the same time, the effect is greatly increased.

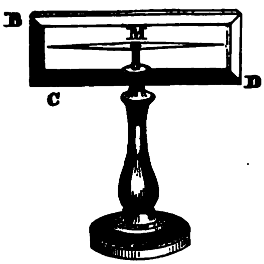


Fig. 96.

The intensity of the thermo-electric current from a single circuit is extremely feeble, and is altogether impeded even by a short length of fine wire; but it may be greatly increased by multiplying the series, as in the voltaic pile. With a series of very short and thin bars of bismuth and antimony, having their alternate ends soldered together, and insulated from each other by pieces of thick paper, a very delicate thermometer may be constructed, which indicates by the deflection of the galvanometer needle, variations of temperature much too minute to be appreciated by any other indicator of heat.

By multiplication of the series sparks have been produced, and electro-magnetic effects have been obtained. A vivid spark was elicited by Chevalier Antinori of Florence, on breaking contact, and Professor Wheatstone successfully repeated the

experiment. He used a thermo-battery of thirty pairs of bismuth and antimony, packed into a cylindrical bundle 1·2 inch long and three-quarters of an inch in diameter, with a coil of insulated copper ribbon 50 feet long and 1½ inch broad. Mr. Watkins, by using a thermo-electric battery of thirty pairs, each plate being 1·5 inch square and 0·33 inch thick, and heating one end of the arrangement with a hot iron, whilst the other was kept cool with ice, succeeded in exciting an electro-magnet to such an extent as to support a weight of ninety-eight pounds.*

M. Melloni and Professor Forbes made valuable use of thermo-electricity in their researches into the nature of heat, as it affords the most delicate means of detecting variations of temperature. The apparatus of Professor Forbes is represented in fig. 97. The thermo-electric battery A, mounted on its stand, consists of thirty-six alternations of bismuth and antimony in very short and thin bars, connected at their ends, but insulated laterally by paper. The terminal elements of the battery are produced at C, to which thick copper wires connected with the galvanometer G are attached. In his experiments the deflections of the needle were examined through a microscope, so that the least movement might be observed. The instrument is so sensitive in its indications that the approach of the hand towards the end of the battery produces a deflection of several degrees.

Fig. 97.

Another source of electricity—the last we have to notice—is derived from the organization of living animals. There are several fishes which possess the power of giving electrical shocks; but those best known in this country are the torpedo and the gymnotus. The former is found in the Mediterranean, and along the shores of France and the south of England. It is a species of ray. The electrical organs lie on each side of the head, and consist of a great number of hexagonal prisms, with their bases directed to one side of the fish and their apices to the other. Upwards of one thousand of these prisms have been counted in a single

* *Dr. Golding Bird's Natural Philosophy.*

organ. The power of communicating shocks depends entirely on the nerves of the fish, for its heart may be taken out without diminishing the effect; but the instant that the nerves are divided the electrical power is lost. The back and the belly are in opposite states of electricity, that of the back being positive, and that of the belly negative; and to receive a shock it is necessary to make a communication between them.

The accompanying figure shows the fish with part of the skin turned over, so as to expose the right electric organ, which presents the appearance of a honeycomb. The mouth is shown at *d*; the ten bronchial apertures at *e e*; *f f* the outer margin of great lateral fin; *g g* two smaller fins, and *h* the tail fin.

Fig. 98.

The electrical properties of the gymnotus, or electrical eel, are better known than those of the torpedo, because some living specimens exhibited in London, first in the Adelaide Gallery, and afterwards in the Polytechnic Institution, have enabled Faraday and other electricians to make experiments with the electricity evolved. The electrical organs are arranged from the head of the fish to the tail on each side of the spine, like a voltaic battery; the end near the head being positive, and the tail negative. The whole power of this living battery is exerted when connection is made between the head and the tail; and if the communication be made between any intermediate parts, the effect is diminished in the same degree as in a voltaic battery under similar circumstances. On putting small live fish into the water with the gymnotus, the latter formed itself into a *circle enclosing* the fish, and sent a charge through the water, *which instantly* stunned its prey. When the hand was held

in the water whilst the charge was transmitted, a shock was felt, though not so strong as when the gymnotus was touched at its two extremities.

Fig. 99.

Fig. 99 represents a gymnotus with the electrical organs laid bare, the skin being turned over on each side. Flat portions and cross divisions appear in parallel lines nearly in the direction of the axis of the body. They consist of thin membranes nearly parallel to each other; their breadth being about the semi-diameter of the body, but of different lengths. In the figure, *a* represents the head; *b* the cavity of the body; *d d* the ventral fin; *e e* the skin turned back; *f f* the external muscles of the fin; *g g* the large electrical organ; *h h* the smaller organ. Fig. 100 presents two views of the entire fish.

Fig. 100.

In a series of experiments with the gymnotus, Faraday clearly established the identity of its peculiar power with that of voltaic electricity of great intensity. It produces a succession of shocks at short *intervals*; it effects electro-chemical deco[illegible] *evolves heat*, [illegible]rks, affects the galvanometer, [illegible]

iron magnetic. An attempt was made to estimate the power of the apparatus, and though the experiments were not very satisfactory, Faraday was led to conclude that a single medium discharge of the gymnotus is at least equal to a Leyden battery of fifteen jars containing 3,500 square inches of glass, coated on both sides and highly charged.

The electrical eel experimented with was forty inches long, but it is found in the rivers and lakes of Venezuela six feet in length. Horses that venture into the pools where the gymnotus abounds, are stunned by their shocks and are often drowned. Humboldt mentions that on one occasion he witnessed about thirty horses and mules driven into a pool occupied by numbers of gymnoti, which glided under the bellies of the animals and discharged through them most violent and repeated shocks. The horses, convulsed and terrified, their manes erect, and their eyes staring with pain and anguish, made unavailing struggles to escape. The electrical energy of the eels, however, became exhausted in less than a quarter of an hour, and those horses that had contrived to keep above water during the attack recovered.

The power of developing electricity appears to be limited to about eight genera of the known fishes. Frogs and some other animals of low organization are peculiarly sensitive to the influence of electricity, but it is very questionable whether they possess any voluntary power of its development. The experiment of the convulsion of the limb of a dead frog by making a communication between a muscle of the leg and a nerve, which has been adduced as a proof of the electricity of frogs, is altogether distinct from that control of the electrical power which is exercised by the torpedo and gymnotus.

That there exists some intimate connection between nervous influence and electricity, there is little doubt. Many attempts have been made, and with some success, to prove that the human body generates electricity; and we have heard it publicly asserted, and maintained by ingenious arguments, that the lungs are galvanic batteries which are constantly generating vast supplies of the electric fluid, which are conveyed by the nerves to the brain, and thence distributed to the whole nervous system to stimulate the vital functions. Dr. Golding Bird affirms, that "it is quite indisputable that the human body is always in an electric state, but of the feeblest tension, never exceeding that evolved by the contact of a plate of zinc with a plate of copper. It increases with the irritability of the person, and appears to be greater in the evening than in the morning, and disappearing altogether in very cold weather."*

* *Elements of Natural Philosophy.*

It appears to be certain that electricity exerts an influence on the germination of seeds, though the experiments hitherto made on this subject have led to no satisfactory results. During the progress of vegetation, and in all the chemical changes that are ever taking place in living bodies, there is no doubt that electricity exerts a powerful influence though its operations cannot be perceived. So far as regards the electricity of plants, Professor Buff has recently ascertained by a series of experiments, that the roots and all the interior portions of plants filled with sap are in a permanently negative electrical condition, whilst the moist surfaces of the fresh branches, leaves, flowers, and fruits are permanently positive. He succeeded also in forming with twelve sappy leaves a feeble voltaic battery, equal in tension to half that of a pair of zinc and copper plates.

From the mysterious connection which is known to subsist between electricity and the nervous system, it seems but a step to attribute the influence of the imagination, and of other affections of the mind, to electrical causes. On this supposition is founded the belief in mesmerism; which assumes that an invisible electric fluid may be emitted by the power of will from the finger-ends of the operator, and be transfused into the system of the patient. It is not our intention to enter that debatable ground; we allude to the subject only as it is one of the most notable forms in which the prevailing opinion of the influence of an electric fluid on the vital functions has clothed itself. It is a deeply interesting question, however, which still remains to be proved, whether the same force which, differently modified, produces electricity, magnetism, and heat, is also to be identified with the immediate stimulus of vitality.

CHAPTER XIX.

ECONOMICAL APPARATUS.

Simple form of apparatus for frictional electricity—Directions for constructing electrical machines—Leyden jars and batteries—Electrometers—Electrophorus—Universal discharger—Voltaic batteries—Electro-magnets—Galvanometers—Observations on exciting liquids for voltaic batteries.

THERE are many students strongly inclined to explore the attractive regions of electric science, whose researches might add greatly to the stock of knowledge, and tend to the elucidation of the mysteries in which the relations of electricity to other forces and to the vital principle are shrouded; but they are deterred from advancing by the cost of the necessary apparatus. We propose, therefore, to assist in removing this obstacle, by giving hints for the construction of apparatus, which any one possessed of a certain degree of mechanical skill can put together himself.

Everything that is absolutely necessary for exhibiting the phenomena of frictional electricity may be provided at the cost of a few shillings, when no great amount of electrical force is required. The author, when a boy, made and experimented with an apparatus of the very simplest kind. His first exciter of electricity was a long bottle of the same shape as those in which eau-de-Cologne was contained, but wider and larger. A piece of black silk, on which a little *aurum musivum* was spread, served for the rubber; and with this bottle, after it had been well dried before the fire, an energetic excitement of positive electricity was obtained by holding it in one hand and rubbing it briskly with the other. For exciting negative electricity a large stick of sealing wax was used. With the glass electric a Leyden jar, consisting of a large glass tumbler coated inside and out with tin foil to within an inch of the rim, was fully charged in half a minute. The discharging-rod was a piece of bent wire. An insulating stand was formed of a piece of wood, mounted on a small phial which was cemented to a wooden base with sealing wax. An electrical machine was afterwards made of equally simple materials. The cylinder was a large phial, into the hollowed bottom of which was cemented an axis,

shaped with a knife to fit into the hollow at one end, and rounded at the other like a spindle. A rudely constructed handle was cemented into the neck of the phial, and it was mounted on two wooden supports fixed into a flat board to serve as the base. The prime conductor was part of the handle of a hair-broom, rounded off at each end and covered with tin foil. It was mounted on a long narrow phial for its insulating support, and pins were stuck into the wood to collect the electricity. The cushion was supported on a wooden prop, and pressed against the bottom of the small cylinder. With this machine, sparks nearly two inches long could be obtained, and it could fully charge the tumbler Leyden jar with about twenty turns of the handle.

With an apparatus so rude and costless in its construction, many of the most remarkable phenomena of electricity could be exhibited; but its diminutive size and rough appearance were scarcely suited for the laboratory of an adult experimental philosopher: we notice it merely to show at what little expense electrical phenomena may be exemplified. We shall now describe a means of providing an apparatus of a better kind, suitable for all experiments with frictional electricity.

A length of stout glass tube, two feet long and an inch and a-half in diameter, which may be purchased at a barometer-maker's for one shilling, serves as an excellent means of exciting electricity by manual friction. It should be varnished inside to prevent the moisture of the atmosphere from condensing and adhering to the glass, and it should be closed at each end with corks. *Aurum musivum* (sulphuret of tin), a small quantity of which may be purchased at an operative chemist's, serves even better than amalgam to stimulate the excitement of electricity by alternating friction.

The glass cylinders for electrical machines may now be purchased of various sizes from the philosophical glass-venders. One of these, six inches in diameter, fitted into a frame consisting of a wooden base and two uprights made of baked wood, will answer for most purposes very well. The prime conductor may also be of wood, covered with tin foil; its insulating support being a glass tube about nine inches long, varnished. Pins, or pieces of brass wire sharpened at both ends, may be stuck into the wood to collect the electricity from the excited cylinder. The cushion, with its flap of silk attached, may be supported on an upright of well baked wood firmly fixed into the wooden base, which will press against the side of the cylinder by the springy nature of the wood. A handle may be purchased to cement into the neck of the cylinder, it being of not much consequence whether it be insulated or not.

Leyden jars may be easily made by coating glass jars with tin foil inside and out, the foil being made to adhere by a thin layer of paste on the foil. A thick brass wire to serve for the connection with the inside coating, should be supported in a firm position in the centre of the jar by a large cork, and a piece of thin wire must be attached to the bottom to make connection with the inside coating. The object of having thick wire is to prevent the dissipation of electricity, which takes place from points and small surfaces. The end of the wire outside should, for the same reason, be covered with a hollow brass ball. Such balls, with screw-holes for the wires, may be obtained at the philosophical instrument makers for threepence each.

In forming a battery of Leyden jars, they should be fitted into a box about half their height, with partitions inside to prevent the jars from being broken by collisions; and the bottom of the box should be lined with tin foil, to form a metallic connection between the outside coatings. All the wires or knobs connected with the insides of the jars should also be joined together by wire. A battery of six quart jars, sufficient to deflagrate small strips of metal leaf, may be thus constructed at a cost of fourteen shillings.

An electrometer presents little difficulty. Four inches of glass tube two inches in diameter, may be cemented on to a wooden stand, having first pasted two narrow strips of tin foil one inch and a-half long opposite to each other inside on the lower part of the tube. The strips of tin foil should have a metallic connection outside the stand. A cork covered with tin foil may be fitted into the top of the tube, instead of a metal cover, allowing a small piece of foil to project in the centre inside for the convenient attachment of two strips of gold leaf. The gold leaves should reach so far down as to be rather below the strips of foil on the side of the tube, taking care in pasting them to the cover, that the metallic connection is not obstructed by the paste or gum.

In making an electrophorus, recourse may again be had to wood covered with tin foil, as a substitute for solid metal. Paste a disc of tin foil nine inches in diameter on a flat board, and over the foil fix a disc of the same size of thick sheet gutta percha, or pour over it some melted resinous cement, made as flat as possible. The conducting insulated plate may consist of a flat circular piece of wood, smaller than the cake of cement; the surface being covered with tin foil, and having attached to the centre of its upper surface a piece of glass tube to serve for the insulating handle.

An universal discharger, insulating stands, and stools may

be made by using short lengths of strong glass tube for the insulating supports. Gutta percha will be found a very convenient substance for many smaller parts of apparatus, as it may be easily moulded into any form by immersing it in hot water, and no known substance is so good an insulator if it be kept dry. By adopting the plan thus sketched out, any person with a little ingenuity and mechanical skill, may put together a very complete and sufficiently powerful apparatus for general experiments with frictional electricity, at a cost of less than two pounds.

Experiments with voltaic electricity, if continued, are more costly, because, in addition to the original expense of the apparatus, there is the constant consumption of the exciting materials. For those experiments, however, which do not require a numerous and powerful combination of plates, voltaic apparatus may be made at even less cost than that for frictional electricity. Zinc plates may be obtained at the metal warehouses of various degrees of thickness, and cut into any size required, at the rate of fivepence the pound. It is not desirable to have the plates less than the eighth of an inch thick. They may be readily amalgamated by dipping them for a few seconds into diluted sulphuric acid, to clean the surfaces, and then sprinkling over them some globules of mercury, which may be rubbed on the zinc with the end of a cork.

The only part of the manipulation in making voltaic batteries that is attended with any difficulty, is the soldering of the metallic connections. The method of doing it is, however, soon acquired, and with a brazier's small soldering iron, a little soft solder, and some muriatic acid, the copper connections, and the binding screws may be soldered on to zinc plates without much trouble. A voltaic arrangement, consisting of two pairs of zinc and copper plates six inches square, may be fitted up in earthenware cells for four shillings. Such a voltaic battery will ignite fine metal wires, decompose water and most other compound substances, powerfully excite electro-magnets, deposit metals from their solutions in the process of electrotyping and electroplating, and, by inducing secondary currents, will give strong electric shocks.

The large flat earthenware cells cost one shilling each; therefore, it is most economical, when many combinations are required, to divide a long water-tight wooden trough into compartments by cementing into it square pieces of slate or thick glass, about an inch and a-half apart.

Electro-magnets are very readily made. Having obtained from a smith some pieces of best soft bar iron, bent into the shape of the letter U, wind round each limb a quantity of covered copper

wire, observing to twist it round each in the same direction and as evenly as possible, and the magnet is complete. The quantity and thickness of the wire depend on the kind of magnet that is required, as previously explained.* Covered copper wire of the size of bell-wire (No. 16), which is the kind generally used for primary magnetic coils, is sold for three shillings the pound. Thirty yards of such wire are sufficient to make a powerful horse-shoe magnet, with iron about half an inch in diameter and five inches long. The wire for inducing secondary currents should be wound upon the primary coil, but separated from it by a covering of silk, varnished; and medical coil-machines for giving shocks by secondary currents require at least 500 yards of fine covered wire. Fine silk-covered copper wire is to be procured nearly as thin as a human hair. Its price is sixteen shillings the pound, and one pound of it contains 18,000 yards. Even finer wire than this is made, and is sometimes used for secondary circuits and for highly sensitive galvanometers, yet it is questionable whether a rather thicker wire that will allow a greater quantity of electricity to pass, is not to be preferred.

To construct a galvanometer in the easiest way, it will be advisable to purchase a common pocket-compass, which may be procured for one shilling. Fix on to the magnetic needle a very thin strip of paper at right angles to it, to serve for the index. Twist round a rectangular open box of pasteboard, into which the compass will fit, a number of turns of fine wire, so that the coil wound round it may be about half an inch wide and about a quarter of an inch in thickness. The galvanometer thus formed should be fitted into a small box open at the top, to enable it to be placed steadily, and through the sides of the box let the wires from each end of the coil project. When used horizontally, the compass should be so adjusted that the coil should be above and in the same direction as the needle; therefore the coil must either be placed in the magnetic meridian, or a small magnet must be placed at one end to keep the needle parallel to it. When the two ends of the wire are connected with any source of voltaic electricity, so that the current may pass through the coil, the needle will be immediately deflected, and the paper index will show the direction and the amount of the deflection. Simple galvanometers of this construction were employed by Dr. O'Shaughnessy on the first telegraphic lines in India, and they were found very efficient instruments at a distance of several hundreds of miles.

* Page 216.

The exciting liquid for voltaic batteries most generally used is sulphuric acid, diluted with water in various proportions. When the zinc plates are well amalgamated, one measure of acid may be diluted with ten of water; but when the plates become worn a weaker solution is desirable. By this dilution local action is avoided, and the effect is equally powerful; because the zinc when worn exposes a larger surface, and is more readily acted on. When powerful action is not necessary, it is better to employ a much more diluted acid, in the proportion even of one to forty. Sulphuric acid, when purchased by the pound, is very cheap. A large stoppered glass bottle, containing ten pounds, may be bought for half-a-crown. Solutions of alum and of salt are good exciters when energetic action is not required. Sulphate of copper is also a good exciter of voltaic electricity; but when used, the zinc should be placed in a separate porous cell, containing diluted acid, or a saline solution; otherwise metallic copper deposits on the zinc, when immersed in the sulphate, and produces counteraction.

The preceding remarks on the construction of economical apparatus, though not perhaps sufficient as explicit directions, will serve at least as hints to those who desire to exercise their ingenuity or to save expense. When neither motive operates, the student may supply himself with better apparatus than he can hope to make, from the manufacturers of philosophical instruments. Mr. Griffin, of Bunhill Row, has a variety of small apparatus in which gutta percha is much used, made very economically, for the purpose of illustrating electrical phenomena in schools, which will be found useful to the young student.

PART III.

APPLICATIONS OF ELECTRICITY.

THE APPLICATIONS OF ELECTRICITY.

CHAPTER I.

ELECTRIC TELEGRAPHS—MEANS OF COMMUNICATING.

First attempts to transmit messages by electricity—Conducting power of the earth—Opinions respecting the cause—Resistance of long wires to transmission—Voltaic currents—Modes of making electric communications—The earth-circuit—Difficulties of insulating wires—Defects of the present system—Underground wires; remarkable detention of electricity in them; plan for preventing it—Submarine telegraphs—Prospect of telegraphic communication with America.

THE practical application of electric force to the requirements of civilized life can scarcely be dated twenty years from the present time; yet within that short period the power of electricity has been applied, with more or less success, to a vast variety of purposes. The transmission of lightning messages, the working of machinery, the chronicling of time, the lighting of streets, the manufacturing of metal utensils, gilding and plating, even sounding the depths of the sea, and the detection of the midnight burglar, are among the many varied uses to which electricity has been directed.

The rapid transmission of electric discharges through extended lengths of wire suggested, at a very early period of the history of electricity, the idea of its applicability to telegraphic purposes. The first plan for transmitting messages by that means of which there is any record, was that of M. Lesarge, of Geneva, in 1774. The signals were made by pith ball electrometers, placed on insulated wires extended between the places with which communication was to be established. The discharge of a Leyden jar, on being sent through the wire at one end, caused the pith balls to expand at the other. There were as many insulated

wires as there are letters of the alphabet, each one serving to indicate a separate letter; and, as the electric discharge was sent successively through the wires, by noticing those on which the pith balls expanded, the words to be transmitted were spelt.

Thus we perceive that at least seventy years before any electric telegraph was in practical operation, a plan for establishing such means of communication had been pointed out. Several other modes of making communications by frictional electricity were invented, which will be noticed in the next chapter; but most of them, like that of Lesarge, required a separate wire for indicating each letter. The discovery of voltaic electricity, and still more the discovery of electro-magnetism, greatly added to the facility of transmitting signals; nevertheless twenty-six wires, one for each letter, were generally considered requisite in the telegraphs that were for some years invented. This number of wires rendered the application of such inventions altogether impracticable on account of the difficulty of insulating separate connections for the many voltaic currents required. The formation of insulated wire connections through which the voltaic current may be transmitted without loss of power, is still the great difficulty in telegraphic communication, even when two wires only are employed for each instrument.

Before we describe the various modes that have been invented for transmitting electric messages, it is desirable that we should explain the means of making communication, and show how the difficulties to be encountered have been overcome.

The experiments undertaken in 1747 by Dr. Watson and other Fellows of the Royal Society, at Shooter's Hill, on the conduction of electricity through wires supported on short posts, not only proved that at a distance of two miles the charge passed instantaneously, but also that the return circuit, of equal length, could be transmitted through the dry ground. In those experiments frictional electricity was employed, the discharge of a Leyden jar having been sent through the circuit. The force of voltaic electricity is comparatively so feeble, that scarcely any sensible current would pass through ground so dry as that which was purposely selected for its dryness in Dr. Watson's experiments; but when plates connected with the two poles of a voltaic battery are buried in *moist* earth, the conduction is so perfect, that at a distance of several hundreds of miles no appreciable quantity of voltaic electricity is obstructed by resistance. The honour of the discovery of the conducting power of the earth has been claimed in recent times, though the fact was established by experiment before the close of the last century.

The "earth-circuit," as it is called, is now made use of in

all telegraphic communications, and is of great practical utility, not only because it diminishes the resistance to the electric current, but it effects also a considerable saving of expense. If wire communication alone were depended upon, it would be necessary to have one wire to conduct the current, and another to convey it back to the battery; but by introducing large copper plates into the earth at the corresponding stations, the return circuit is completed through the moist ground, and one wire is saved. This saving of wire, which in the case of a single circuit amounts to one-half, is not, however, proportionally great when several circuits are employed; for a single wire will serve for the return circuits of any number that may be used, in the same manner as the earth at present does.

The annexed diagram will explain more clearly the action of the earth-circuit. The letters A B represent the wires making

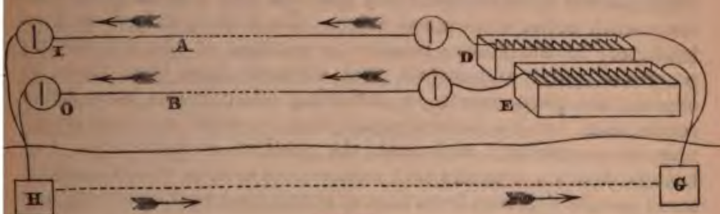


Fig. 101.

communications between the batteries D and E, and the telegraphic instruments I O at the receiving station. The electricity from the copper end of the battery D would be conducted along A through the instrument I, and by the wire K to the earth-plate H. It would be then transmitted through the earth, on its return to the battery, in the direction of the arrows, to the other earth-plate G, and thence it would find its way to the zinc pole of the battery D, and complete the circuit. In the same manner the electric current from the copper end of the battery E would be transmitted through the wire B, and would complete its circuit also by means of the earth-plates G H, and would traverse the course indicated by the arrows, and return to the zinc end of E. Though both electric currents traverse the same wire, from the instruments I O to the earth-plate H, and are thence transmitted through the earth to a single plate G at the transmitting station, there is no mingling of currents, the electric current of each battery being kept as distinct as if separate wires were used both for the transmitted and the return current. It would, *indeed*, be as impossible for the separate currents transmitted

from the two batteries to be mingled together, as it would be for the written contents of two letters enclosed in the same mail-bag to intermix.

The entire separation of the two currents, when transmitted through the earth, also takes place when a single wire only is used for the returning portion of the circuit. Suppose, for instance, the plates H and G, instead of being buried in the earth, were directly connected by an insulated wire, the current from each battery would be equally separate; but the resistance offered by the wire being very much greater than that of the earth, not nearly so much of the power of the battery would be transmitted.

Pure water is estimated to offer three milllion times the resistance of copper to the passage of an electric current. It seems, therefore, an anomalous fact, that the moisture of the earth should conduct electricity between two distant points so very much better than metal wires. The fact is, indeed, so contradictory to the known relative proportions of the conducting powers of water and metals, that attempts have been made to explain the phenomenon by assigning other causes than mere conduction. It has been assumed that the earth is a vast reservoir of electricity,* and that the positive current from the battery E, when it enters that reservoir, is at once transferred by some process different from that of conduction to the corresponding plate.

This opinion has received countenance in quarters that have given it more importance than it would otherwise seem to deserve, especially when it is well known that an imperfect conductor can compensate for its defective state of conduction by increase of volume. Take, for instance, the two metals copper and iron. Iron offers seven times the resistance of copper to the passage of an electric current; but by proportionally increasing the size of the iron wire, a current of electricity will be transmitted through it as readily as through the better conducting metal. In the same manner, by bringing into conducting action a large body of interposed moist earth, the electricity, which would not pass through a small quantity, is transmitted without any apparent resistance when a large sectional area is included between the plates buried in the ground.

Professor Matteuchi made numerous experiments with a view to ascertain the amount of resistance offered by the earth to an electric current, and the mode by which the transfer is effected,

* *Electric Telegraph Manipulation*, by C. V. Walker.

the result of which is decidedly in favour of the opinion that the transmission is produced directly by means of conduction only. "If," as he observes, "the effect was caused by immediate absorption and reproduction, a mere contact with the earth would be sufficient; but it is essential that the plates buried in the ground should present a large surface, without which there is a comparatively small quantity of electricity transmitted." The Electric Telegraph Company generally bury a quantity of sulphate of copper with the earth-plates, so as to surround them with a good liquid conductor, which serves, practically, to increase the conducting surfaces that connect the poles of the battery with the earth.

The resistance of a wire to the passage of an electric current increases with its length, but not in direct proportion. In experiments by Professor Morse, of the United States, when using a battery of 100 pairs of plates, it was found that when the current was transmitted through one mile, the battery power was diminished one-third; at a distance of two miles, one-half the power was transmitted; and at a distance of five miles only one-fifth the quantity of water could be decomposed in the voltameter, compared with the decomposing power of the battery when no length of wire at all was interposed. The resistance proceeded in a diminishing ratio until a distance was attained beyond which there appeared to be little further diminution of the power transmitted. The same result has been observed in the telegraph lines in England. The diminution of the electric current by resistance of the wire is not much greater at a distance of 200 miles than it is at a distance of 100, provided the insulation be very good; but if the insulation be imperfect, of course, the loss of power will increase with the length of the circuit.

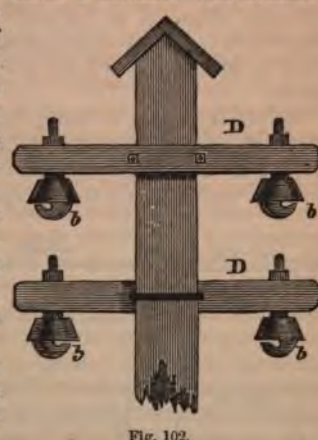


Fig. 102.

The difficulty of effecting perfect insulation of the wires is the greatest impediment to the establishment of telegraphic communication. The wires are either supported on posts, or they are covered with gutta percha, and laid in trenches under ground. The *former plan* was at first generally adopted. The posts *are about fourteen* feet high, and cross arms of wood

102), eighteen inches long, are fixed to them cross wise, about ten inches apart. At each end of the short wooden arm balls of earthenware *bb* are attached, in the sides of which nicks are made to hold the wire; and these globes are covered with a cap of galvanized iron, to protect them from the rain, and to prevent the deposition of dew. The earthenware, being an imperfect conductor of electricity, insulates the wires from the posts, and prevents the electric current from passing down them to the earth in wet weather. Balls of glass are beginning to be used instead of earthenware, as that substance is a better insulator. The most recently contrived form of insulator consists of a glass globe supported on the frustrum of a cone with a bevelled notch at the top of the globe for the wire to rest in. At the bottom an iron screw is fixed in the glass for attachment to the posts. This form of insulator is shown in fig. 103. The posts are generally made of wood, and in the first instance great care was used to insulate the arms to which the insulators are attached from the post. This precaution is now disregarded, and cast iron posts are beginning to be used instead of wood.

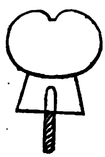


Fig. 103.

Iron wire, one-sixth of an inch in diameter, and galvanized to prevent corrosion, is the kind used in the telegraph lines of this country. As many as thirteen of these wires are attached to the posts on the North-Western Railway, near London. Some of them extend to Liverpool and Manchester, some to Glasgow, and some are connected with the intermediate towns.

By placing wires forming short circuits, in close proximity to those of long circuits, the difficulty of insulation on the longer circuits is considerably increased. Let D I represent a wire extending from London to Liverpool, and E O one extending from

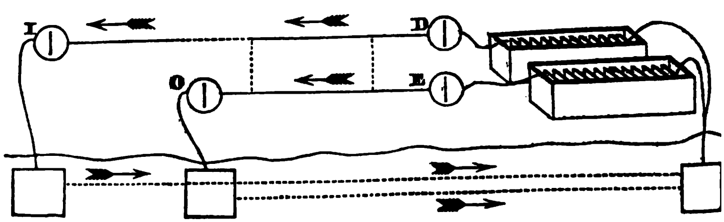


Fig. 104.

London to Birmingham, both supported on the same posts within a few inches of each other. In a damp state of the atmosphere, when there is any defect in the insulation of the

the electricity in its course along D I will be continually to the wire E O, as shown by the dotted lines; for it can t means take a shorter return-circuit by passing to the late of O, and thus return by the plate, which is common wires, to the battery of D, instead of traversing the whole long circuit to I. In this manner it not unfrequently s that so much of the electric current is diverted that the ph instruments cannot be worked.

he opinion of the author, the escape of electricity from the greatly facilitated by the exposure of the wires in such roximity to each other without any insulating coating. ught this subject before the notice of the British Associa- the Advancement of Science at their meetings at Ipswich lfast; and in the papers read by him on those occasions eavoured to show that the greater part of the loss of elec- in damp weather is owing to the communication from wire through the moist atmosphere, and is not occasioned ective insulation at the posts. In this opinion several phic engineers now agree. To secure perfect insulation, ected by rain or fog, it would be necessary to varnish or ise insulate the surfaces of the wires.

the opinion of many electricians that the low intensity aic electricity effectually prevents it from passing from wire, even through an atmosphere of fog. This opinion ever, opposed to sound reasoning on well-established for though on the small scale in which experiments conducted in a laboratory, no appreciable quantity of electricity will pass through the air, such limited means rvation are not to be depended on when the surfaces l are very great. Each iron wire from London to Liver- poses a surface of not less than 45,000 square feet; and n several surfaces of that extent, only six inches apart, an be little question that a large quantity of the electric must be transferred and lost when the air is charged with e.

wires on the telegraph lines in India are thicker, and they ced at a greater elevation than in this country. The r wires were found to be necessary to enable them to the large birds and the monkeys that perched and con- d upon them; and greater height was required to allow elephants to pass underneath. Dr. O'Shaughnessy, the tendent of the East India Company's lines, has also in- d the plan of making the posts stronger as well as higher, ch means they may be placed at greater distances apart; e *than eight posts* being required in a mile. In this

country it has been customary to consider the protection of a railway essential to the establishment of telegraph lines. The protection, however, that a railway affords is more imaginary than real; and in India the completion of a system of telegraphic communication over 2,000 miles of country has preceded the construction of railways.

When the atmosphere is in an electrical condition, the telegraphic instruments are often disturbed, though no current is transmitted along the wires from the batteries; and during thunder-storms the wire coils have been destroyed by lightning. To prevent this disturbance by atmospheric electricity, lightning-conductors are attached to the posts at certain distances.

In the underground plan of laying down telegraphic lines, the copper wires are covered with gutta percha, and are then laid in trenches two feet deep. This plan is more expensive than the suspension of wires on posts, and it was not, until recently, adopted in this country, excepting under special circumstances, such as connecting the wires with the telegraph stations in towns by passing under the streets. In these cases it is usual to protect the wires by enclosing them in iron tubes. In Prussia the underground system was at first generally adopted; but it has given place to the suspension on posts, as the gutta percha coating was attacked by vermin when not enclosed in tubes.

The monopoly of the railways by the first established electric telegraph company in this country, induced the other companies which were subsequently established, to adopt the underground system, and such lines have been constructed from London to various parts of the kingdom. The superior insulation thus obtained, has also induced the original company to lay down wires in the ground covered with gutta percha. Experience has, however, proved that gutta percha cracks when buried in the ground for three or four years, and the insulation becomes impaired. Some other material must, therefore, be discovered to answer the purpose more durably, or the over-ground plan must be had recourse to. In France, and on the continent generally, the wires are supported on posts.

A most unexpected difficulty was found to arise from the underground wires, which threatened to prevent the use of those electric telegraph instruments in which the voltaic current always passes in the same direction. When the submarine cable to the Hague was laid down, a recording telegraph was tried which makes marks on paper by electro-chemical decomposition, but instead of making dots, as was customary when transmitting through suspended wires, the instrument drew uninterrupted

lines on the paper. Attention was immediately directed to the cause of this continuity of action, which was first made public by Faraday, in a lecture at the Royal Institution, in January, 1854. He ascertained that this peculiar effect was occasioned by the detention of the electricity in the wire, which, with its coating of gutta percha surrounded by conducting moisture, becomes in the condition of the interior lining of a Leyden jar. A length of one hundred miles of wire covered with gutta percha and immersed in water, was found to retain the charge of a powerful voltaic battery for upwards of a minute after connection with the battery had been broken. The wire when thus circumstanced becomes in fact an elongated Leyden jar, and, in the same manner as a Leyden jar, retains a portion of the electricity after it has been discharged. Faraday obtained forty successive shocks from an immersed wire, after contact had been broken with a battery consisting of about 300 pairs of plates. During some experiments which the author was kindly permitted to make at the Gutta Percha Works, in the City Road, with a view to remove the difficulty occasioned by the detention of the electricity in underground wires, he witnessed the setting fire to a fuse full half a minute after battery contact, the current having passed through one hundred miles of wire covered with gutta percha and immersed in the canal.

This detention of the electricity does not materially affect the action of the needle telegraph, in which the direction of the voltaic current is continually reversed; and Mr. Varley, by applying that principle to the chemical telegraph, succeeded in overcoming the difficulty of working it to the Hague. After each signal the wire is connected with the earth, and a reversed

Fig. 105.

current is sent through the wire before another signal is made, by which means the marks on the paper are made nearly as distinctly as when the transmission is through wires suspended in air. By adopting the same principle, the difficulty which attended the working of the copying telegraph through submarine wires has also been overcome.

In forming a submarine telegraph, the plan that has been found most successful is to enclose several copper wires, coated separately with gutta percha, within a hollow wire cable, of which the insulated wires form the core. Cables of this kind, resting on the bed of the English Channel and of the German Ocean, now serve to transmit messages between England and the continent, and answer the purpose remarkably well.

Fig. 105 shows the mode of enclosing the wires in their outer casing of iron. The protruding end C exhibits the copper wires covered with gutta percha, and twisted spirally; B is a covering of hempen twine, to form the core; A the cable of iron wire, and the other end shows a section of the whole.

The principal objection to that plan is its cost. The cable from Dover to Calais, with four thin copper wires enclosed, cost, we believe £20,000.

In the submarine cable, from the coast of Suffolk to the Hague, each wire is covered separately with an iron wire rope, and is laid down singly. By this plan, the wires can be carried from shore to shore much more readily than when in a combined thick cable, and there is much less risk of communication from wire to wire by defective insulation. The practical results of the system are not, however, so satisfactory, for the cost of repairing the wires during the first half of the present year, exceeded £2,000, whilst the cable from Dover to Calais has cost nothing in repairs; and though several times dragged up by anchors, it has not suffered material injury.

Copper wire is used for submarine telegraphs, because copper is a much better conductor of electricity than iron; and as a thinner wire answers the purpose of conduction, it may be more easily insulated, and forms a smaller core for the external cable. This mode of forming submarine telegraphs is, however, in the author's opinion, open to many objections. All the failures that have occurred in endeavouring to establish submarine telegraphic communication have arisen from the breaking of the wires. The experimental wire across the English Channel broke shortly after the first signal was transmitted; it was the same with that from Holyhead to Dublin, though protected by a thick wire covering; and the first wire from Donaghadee to Port-Patrick was cut in two by mistake. It seems highly objectionable, therefore, to continue the use of thin copper wire under circumstances which experience has shown require additional strength. The rejection of thick iron wire, on the ground that it is more difficult to insulate than thin copper of equal *conducting* power, seems to be not well founded. As iron *conducts* electricity with less facility than copper, any defect in the

insulating coating will have a less injurious effect than if an equal or a much smaller surface of copper was exposed; therefore, the difficulty of insulation would not be increased by the use of the stronger and less perfectly-conducting metal. The cable, it is true, would be thicker; but its strength would be increased in a greater proportion, and there would be much less danger of failure.

Having succeeded in connecting England with the continent of Europe by submarine telegraph, so as to transmit intelligence instantaneously from London to Berlin and to Paris, the problem that remains to be solved is, to effect similar communications with America, the East Indies, and Australia. It has, even at present, almost resolved itself into a question of money. Such a cable as that which now connects France with England might, by proper arrangements and with the aid of steamships be stretched across the Atlantic. The cost of the cable, with the expense of laying it down from the western coast of Ireland to New Brunswick, would not amount to one million pounds sterling; and for the accomplishment of a great national object, so important to commerce and to our colonial government, the expenditure of one million is scarcely worth consideration as an objection. But if the mode of communication we have indicated as most suitable were adopted, and a single iron wire were employed, the cost would be greatly reduced, and the difficulty of laying down the wire would be for the most part removed.

A single wire telegraph between England and America would, in the first instance at least, be amply sufficient. A thick galvanized iron wire or rod, coated with gutta percha, and that coating protected for some distance by a covering of iron wire, might be constructed at a comparatively small cost, and would be much stronger and form a more efficient conductor of electricity than a thin copper wire. Such a telegraph wire might be laid down between the west of Ireland and America for *less than* £100,000. It should be remembered, also, that in the depths of the Atlantic beyond the range of animal or vegetable life, and where no anchors ever reach, the telegraphic wire would be free from the dangers to which it is exposed in shallower seas. There is, indeed, no practical difficulty in extending a telegraph wire to America that may not be easily surmounted; and with the almost certain prospect of instantaneous communication between the old and new world, for one-tenth the cost of building a bridge across the Thames, it cannot be long before that event is realized.

A beginning has indeed been made in the plan of laying down the *more costly kind of* cable. New Brunswick and Newfo[illegible]

land are already in telegraphic communication, and a company has been formed to extend the wire to the west of Ireland. The funds have been already provided, to the amount of £250,000, and it is anticipated that the submarine line will be completed before the end of next summer. Another company is also in the course of formation to bring a telegraphic wire to India; and the Mediterranean is now being crossed by the talismanic wires.

The extent of telegraphic communication in Great Britain at the present time is about 7,500 miles, in France 3,000, Prussia 5,000, Austria 4,000, in India 2,000, and in America not less than 17,000 miles.

CHAPTER II.

ELECTRIC TELEGRAPHS—SIGNAL INSTRUMENTS.

Progress of telegraphic invention—Instruments invented by Lomond, Reizen, Soemmering, Ronalds, Ampère, Schilling, Gauss, Steinhil, Alexander, Davy—Cooke and Wheatstone's needle telegraphs—Action of the needle telegraph—Rapidity of transmission—Henley's magneto-electric telegraph—Breguet's Semaphore.

The form of instrument first contrived by Lesarge, in 1774, for transmitting telegraphic messages has been already noticed. In 1787 M. Lomond so far simplified the means of telegraphic communications, as to point out the way of transmitting signals with a single wire. He adopted Lesarge's plan of using a pith ball electrometer ; and he indicated the letters of the alphabet by the number of the divergences of the balls, and the variation in their duration. With this telegraph M. Lomond communicated between different rooms in his house, the force employed being that of an electrical machine.

Ten years afterwards a very ingenious application of electric light to telegraphic purposes was made by M. Reizen. He pasted on a pane of glass strips of tin foil with spaces cut out in the form of letters of the alphabet, so that when an electric spark was transmitted through the convoluted foil, the light at the interstices presented the form of the letter to be indicated. As a means of indicating the signals this mode was perfect, but it required a separate wire for each letter. Several other ingenious contrivances were invented on the continent for the transmission of signals by frictional electricity at the commencement of the present century, but none that deserve special notice in this summary.

The first known application of voltaic electricity to the transmission of signals was that of M. Soemmering, in 1809, as announced to the Academy of Sciences of Munich. The bubbles of gas arising from the decomposition of water served to indicate the letters to be transmitted. Thirty-five gold wires were inserted through the bottom of a long narrow glass vessel, half filled with acidulated water. The circuit of the voltaic battery was passed through the water by connecting any two of the wires with the opposite poles of the battery. The instant that

connection was made and the circuit completed, bubbles of hydrogen gas rose from one of the wires, and of oxygen from the other. The hydrogen gas, being in the proportion of twice the volume of the oxygen gas, could be easily distinguished. Every wire signified a letter of the alphabet, or numeral, and the wire from which the hydrogen was successively evolved was the letter to be noticed. By this means a very efficient mode of signalling by electro-chemical decomposition was arranged; but the practical difficulty of requiring so many wires would, under even more favourable circumstances, have prevented its adoption. By a simple modification of the instrument, however, it may be easily adapted to the transmission of all required signals with a single wire. If two gold wires only were inserted through the bottom of the glass vessel, the hydrogen gas might be made to issue from one or the other by reversing the poles of the battery, in the manner now done with the needle telegraph, as will be presently explained. By this means the issue of hydrogen gas from the right hand wire might signify one letter, and from the left wire another. A repetition of the jets of gas, from either of the wires alternately, might signify other letters; and thus the whole alphabet might be indicated by a single circuit, in the same manner, and almost with equal facility, as it is now done, by deflecting a magnetic needle to the right hand and to the left. To call attention when a message was to be transmitted, M. Soemmering proposed to liberate a wound-up alarum by means of the evolution of the gas generated during the action of the telegraph.

A modification of M. Soemmering's telegraph, by which all the signals might be transmitted with two voltaic circuits, was, indeed, proposed by M. Schwieger. By his plan the variations of the symbols were caused by employing two batteries of different powers, which consequently evolved different quantities of gas, and also by making varied intervals in the emissions of the gas from the gold wires.

A very remarkable form of electric telegraph was invented by Mr. Ronalds in 1818, in which, however, he reverted to frictional electricity for the actuating agent. At each corresponding station he had a revolving dial carried round by the seconds hand of a clock. On this dial the letters of the alphabet were marked, and they were seen in succession through a small aperture, near to which was suspended a pith ball electrometer. The two dials were made to revolve exactly together, so that when a letter appeared at one aperture the same letter appeared also at the aperture on the corresponding dial. The pith balls were maintained in a diverging condition durin- -ransmis-

sion of a message; and the instant that the letter required to be indicated came in sight at the transmitting station, the electricity sent through the communicating wire was discharged, and the collapse of the pith balls directed the attention of the observer to it at the receiving station. In this manner communications could be transmitted with a single wire. The synchronous movement of the two clocks, to insure the same letters appearing at the same time at each instrument, was obtained by adjusting them by an electric signal before each message.

Mr. Ronalds was very persevering in his attempts to perfect his telegraph, and to bring into notice the advantages of electricity as a means of telegraphic communication. He, at great expense, insulated eight miles of wire in glass tubes on the lawn of his house at Hammersmith, through which the telegraph was worked. He endeavoured to direct the attention of the government to the subject; but he met rebuff instead of encouragement. The government officials told him that "*telegraphs are of no use in time of peace*, and that the semaphore answered all required purposes"! It is in this manner that attempts at improvement are generally received by persons in authority. They will not give themselves the trouble to investigate the merits of any invention, but wait until it has struggled through all difficulties, and forces itself on their notice. Of the very many useful inventions that are lost in the struggle which inventors have to make, little or nothing is known. In the case of Mr. Ronalds, finding his endeavours to be hopeless, he not long afterwards quitted England, and took no further steps to improve a system then considered by the government of so little value, but which is now, year by year, becoming of more and more importance as a means of general communication.

The discovery of electro-magnetism by Professor Œrsted presented a new mode of transmitting signals by voltaic electricity; and in 1820, M. Ampère laid before the Academy of Sciences a method which he had contrived for sending messages by the deflection of magnetic needles surrounded by coils of wire; his plan, however, required a separate wire for each symbol.

The Baron de Schilling made a great practical improvement on the plan of Ampère. He first constructed, at St. Petersburg, in 1832, a telegraph in which five magnetic needles were employed. By the single deflection of these five needles, alternately to the right or to the left, ten primary signals were obtained, without the necessity of two needles being used at the same time. The *combination* of a few such signals was made *to express whole words* or sentences. He also invented

alarum so constructed, that the motion of one of the magnetic needles allowed a weight to fall, and sound a bell. Another of Baron de Schilling's plans of a later date, was to use only one magnetic needle; and by counting the deflections to the right or to the left, the letters of the alphabet were indicated.*

Not long after the discovery of magneto-electricity by Professor Faraday, Messrs. Gauss and Weber of Göttingen applied the magneto-electric machine to the transmission of messages. They employed only a single needle to make all the symbols, and a telegraph operating on that principle was worked at Göttingen for a distance of a mile and a quarter.

Dr. Steinheil's telegraph, invented in 1837, presented great advancement in the application of electricity to telegraphic purposes. It is spoken of by Mr Highton as a perfect arrangement, and as one which "may well put to shame many of the plans afterwards patented in this kingdom." Dr. Steinheil could either transmit messages by sound or by making permanent marks on paper. This telegraph consisted of a single circuit, half of it being wire, the other half the earth, and the stations between which the telegraph worked were twelve miles apart. One or two magnetic needles were employed, as required, and they were deflected by magneto-electricity. When it was desired to telegraph by sound, the needles struck against either of two bells differently toned. To enable the instruments to record the message, the needles were furnished with small tubes holding ink, and by their motions dots were made on paper properly moved in front of them by wound-up mechanism, one needle making dots in one line, and the other needle making dots in a line underneath the former. Not more than four dots were required to make any of the letters, and some were marked by a single dot. The mode of recording on paper the messages transmitted by this means will be rendered more intelligible by the annexed representation of the symbolical alphabet made by the penholding needles.

A B D E F G H CH SCH I K L M N O P R S T V W Z

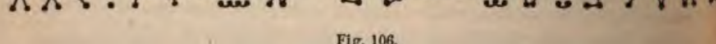


Fig. 106.

Before the year 1837 scarcely any attempt besides that of Mr. Ronalds' had been made in England to improve the electric telegraph; but that year seems to mark the commencement in this country of the direction of inventive genius to electric telegraphs, which have since progressed most rapidly. In June, 1837,

* *The Electric Telegraph*, by E. Highton.

the electric telegraphs of Mr. Alexander and of Mr. Davy were publicly exhibited in London. The former operated by removing screens from before letters of the alphabet. The letters were painted on a frame, and were concealed from sight by small light screens attached to the magnetized needles, the deflection of which, when the voltaic current passed through the coils, successively exposed the letters to view. Mr. Davy's telegraph was constructed on the same principles, but the letters were painted on ground glass illuminated from behind, consequently they were more distinguishable. Both these telegraphs required a separate voltaic circuit for each symbol. It is, indeed, curious to notice in the progress of telegraphic invention, that notwithstanding the impracticability of using a telegraph which required so great a number of wires, notwithstanding also that the mode of transmission by one or two wires had been often pointed out, how resolutely each inventor in succession adhered to the appropriation of a separate wire for every symbol to be transmitted.

In 1837, Mr. Cooke and Professor Wheatstone succeeded in establishing the first working electric telegraph. The patent taken out by Messrs. Cooke and Wheatstone in 1837 was for a needle telegraph in which the symbols were made with five needles. In the following year the arrangement was simplified so far as to reduce the number of needles to two. That arrangement of the double needle telegraph is the one that continues to be generally used in this country.*

It would occupy far too much space to give an account of all the modifications and improvements in the modes of transmitting messages that have been since introduced. Upwards of eighty patents for electric telegraphs have been obtained in England since the first of Messrs. Cooke and Wheatstone's, and

* A dispute, much to be regretted, has arisen between Messrs. Cooke and Wheatstone about their respective claims to be the inventors of the electric telegraph. The question was first mooted in 1841, and arbitrators were then appointed to decide it; the late Professor Daniell having acted on behalf of Professor Wheatstone, and Sir M. I. Brunel on behalf of Mr. Cooke. The decision at which the arbitrators arrived was: "Whilst Mr. Cooke is entitled to stand alone as the gentleman to whom this country is indebted for having practically introduced and carried out the electric telegraph as a useful undertaking, promising to be a work of national importance; and Professor Wheatstone is acknowledged as the scientific man, whose profound and successful researches had already prepared the public to receive it as a project capable of practical application; it is to the united labours of two gentlemen, so well qualified for mutual assistance, that we must attribute the rapid progress which this important invention has made during the five years since they have been associated." In a controversy recently published on the subject, it is stated that Professor Wheatstone was paid by the Electric Telegraph Company for his share of the patents £30,000 in cash; and that Mr. Cooke was to receive out of the profits of the Company, and in shares £96,000.

numerous other similar inventions have been patented on the continent and in America; but it will be sufficient to limit our notice to those that possess the most distinguishing features.

The needle telegraph is simply a delicate galvanometer constructed of numerous coils of very fine copper wire covered with silk. The magnetized needle is placed upright, the lower end being slightly heavier, to make it assume a perpendicular position when in its normal state. There are two oblong coils of very fine wire connected together, between which the needle is poised. The object of employing two connected coils instead of a single one, is to allow the axis that carries the needle to pass between.

Fig. 107.

The diagram exhibits a perspective view of a mounted needle. The axis is supported within the coil i k, so as to allow the needle to vibrate with the least possible resistance from friction. The needle is fixed to the axis inside the coils. An outer needle h was originally employed as an index, the poles of which were in a reversed position to those of the inner one, so that the

magnetic action of the coil, when the current passed, tended to deflect them both in the same direction and with increased force. The index is, however, now generally made of a light strip of wood, but by that means some of the power of the coil is lost. When the voltaic current is sent through the coils the needle is instantly deflected either to the right or to the left, according to the direction in which the current passes; the connections with the copper and the zinc ends of the battery being so arranged that they may be reversed on moving the working handle either to the right or to the left.

The arrangements of the instrument to reverse the directions of the voltaic current are rather complicated; but the principle on which they depend will be readily understood by inspection of fig. 108. The letters D E represent the communicating wire, in which there is a break at the transmitting station. Close to this break is placed a moveable piece *b d*, that slides laterally, and it is connected with the two poles *c z* of the voltaic battery. The upright wires at *b d*, each connected with the zinc pole *z*, are insulated from the wire *e*, which is connected with the copper pole *c*. It will be evident, therefore, that if the piece to which these wires are attached be shifted towards the right, the wire *e* will touch the communicating wire at D, and *b* will touch E. By these contacts with the two ends of the communicating wire, the circuit of the voltaic battery will be completed, and an electric current will be transmitted from *c* to D, in the direction of the arrow, to the earth-plate H, thence to the receiving station, and back again, through the instrument I, to the zinc pole *z*. The lateral movement of the wires connected with the battery to the left, will, in the like manner, bring *e*, which is in connection with the copper pole, to E, and *d* of the zinc pole to D, and the current will then be sent in the opposite direction, viz., from the copper pole of the battery to E, through the instrument I to the receiving station; and it will return by the earth-plate H to the zinc end of the battery. By rapidly changing the positions of the wires from side to side, the voltaic current may be thus reversed several times *in one second*; and each reversal of the current *will change the direction* in which the needle is deflected.

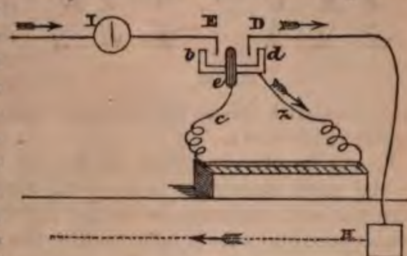


Fig. 108.

By the adoption of what is called a code of signals, the deflections of a single needle may be made to denote all the letters of the alphabet. The code for a single needle telegraph is shown in the annexed diagram; the number of deflections of the needle to the right and left being made to indicate the letters under which the marks are placed. The deflections of the symbols for each letter commence in the direction of the short marks, and end with the long ones. Thus it will be seen, that to indicate the letter D the needle is first deflected once to the right and then once to the left; whilst two deflections, beginning with one to the left and ending with one to the right, signify the letter R.

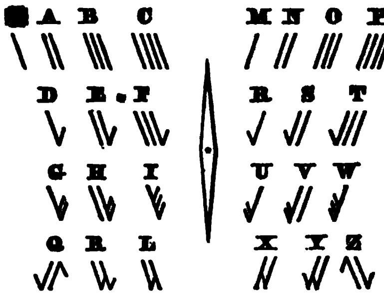


Fig. 109.

It will be observed that all the symbols in the left division of the scale commence with a right-hand deflection, and end with the left; whilst those on the right division commence with the left and end with a deflection to the right. When the double needle telegraph is used, the number of successive deflections requisite to denote all the letters of the alphabet are fewer, because, with two needles, capable of being pointed in both directions, six primary symbols are obtained by a combination of the deflections of the two needles.

A practical knowledge of the working of the needle instruments is generally acquired within a month. Some of the telegraph clerks have become so expert by continued practice, that they can transmit as many as 150 letters a minute with the double needle instrument. It is, however, much more difficult to read the symbols than to transmit them; and as the messages must be written down, the rapidity of transmission is practically limited to the speed of writing, which seldom exceeds 100 letters a minute, and that is considerably faster than the average rate of transmission.

In the early stages of the progress of the electric telegraph it was considered very important to have the means of calling attention when a message was to be transmitted, and there were many contrivances for ringing bells at the distant stations. The use of alarums has, however, been discontinued at all the *principal* stations of the Electric Tele[illegible] Company. The

sound of the needles striking against the pins fixed in the dial to limit the range of the deflections is generally sufficient to call the attention of the clerks, who are constantly seated near their instruments. When alarums are required, bells are sounded by liberating a wound-up mechanism by withdrawing a detent by means of an electro-magnet.

Fig. 110 represents a front view of a double needle instrument. The handles are held by the clerks, and by moving one or both to the right or to the left one or both of the needles are correspondingly deflected. In transmitting messages in this manner it is customary for the clerk at the receiving instrument to intimate at the end of each word that he understands, by giving a single deflection of the left-hand needle to the right; when he does not understand, and requires the word to be repeated, he deflects the same needle to the left.

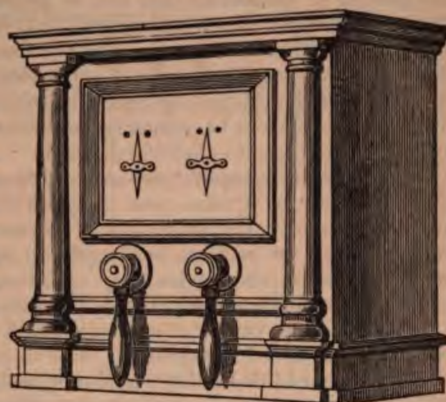


Fig. 110.

There have been many patents obtained for modifications of the needle telegraph; but they are all identical in principle with the original one of Messrs. Cooke and Wheatstone. One of the objects that it has been the endeavour to attain, is a dead beat of the needle without any vibration. It is now the practice to use a piece of lozenge-shaped magnetized steel instead of a needle within the coil, that form having been found to be more sensitive to the action of the voltaic current, and to produce less vibration.

One arrangement of the needle telegraph quite distinct from the foregoing, is the magneto-electric telegraph invented by Mr. Henley. We have already noticed several attempts to apply magneto-electricity to telegraphic purposes, but that of Mr. Henley is by far the most successful. Two armatures, in close proximity to strong permanent magnets, are made to revolve rapidly by *striking* down projecting levers; and the r[illegible]ns *of the armatures* induce currents of electricity alo[illegible]

municating wires that react on the magnetic needles, and cause them to be instantly deflected.

The electricity generated in this manner is small in quantity, and of comparatively great intensity, therefore more liable to be diverted from the circuit by imperfect insulation. Another difficulty which this form of telegraph has to contend with is, that the needle sends signals in one direction only. Two communicating wires are consequently required to obtain the same combination of deflections that can be given with a single wire when a voltaic current is transmitted. It is a great advantage of this system that it dispenses with the use of voltaic batteries, which are very troublesome and expensive; and it remains a question to be determined by practical experience, whether this advantage is sufficient to counterbalance the objections attending the use of the magneto-electric telegraph.

The electric telegraph instrument formerly used on all the telegraph lines in France was invented by M. Breguet. It transmits symbols resembling those of the semaphore. Moveable arms, working on centres, are made to assume positions at certain angles in the circles they describe, and the combinations of those different positions in the two arms allow of their expressing a great variety of symbols, which correspond with the code of the discarded semaphore.

We have heard this kind of signal telegraph highly commended, and have seen it working with great rapidity and precision. It possesses the advantage, from the great variety of combinations of which it is capable, of not requiring successive actions to indicate any letter of the alphabet or numeral. The movements are effected by electro-magnets, which give rotary motion to wheels that carry round the arms; and the accuracy with which it is necessary that the semaphore should be pointed to the required angles renders very nice adjustment of the instruments indispensable.

CHAPTER III.

ELECTRIC TELEGRAPHS—RECORDING INSTRUMENTS.

Morse's telegraph—Modification of it by the Electric Telegraph Company—Bain's dotting telegraph—Brett's printing telegraph—Copying telegraph—Mode of transmitting copies of writing—Regulation of the instruments—Rapidity of the copying process—Means of maintaining secrecy.

In the telegraphic signal instruments, the symbols are exhibited for an instant and disappear; those we are about to describe record on paper the messages they transmit. More errors occur in reading the evanescent signals than in the transmission of them; but as the recording instruments impress what is transmitted, the message may be read at leisure when the whole is completed.

The most successful of the instruments that impress arbitrary symbols on paper is that of Professor Morse of America, invented in 1837, and since considerably improved. The transmitting part of the instrument is of the very simplest kind, and might be carried in the waistcoat pocket. It consists only of a key, like the key of a musical instrument, which, on being pressed down, makes connection with the voltaic battery for a shorter or longer duration, according to the time that the finger of the operator is pressed upon it. The receiving instrument is more complicated. By means of clock mechanism, a small drum, round which a long strip or ribbon of paper is rolled, is made to revolve. The paper as it is unrolled from the drum passes under a lever attached to the keeper of an electro-magnet, armed with a projecting point. When the electro-magnet is put into action, the lever is drawn down on the paper, and the point makes an indentation in it. As the paper is continually drawn along, the length of the indentation varies from a mere dot to a long stroke, according to the time that the lever continues to be pressed against the paper; and by varying the duration of the pressure of the paper on the transmitting key, dots or strokes are impressed on the paper at the receiving station. Conventional symbolical alphabets have been arranged, by [illegible]er-*nation of the dots* and strokes, which, with a lit[illegible]

may be easily read. The symbolical alphabet that has been adopted in this country, when a modification of Morse's system is used, is represented in fig. 111.

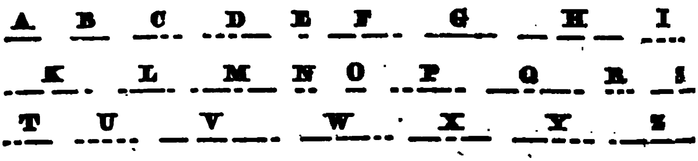


Fig. 111.

As the mechanical power required to impress marks on the paper is stronger than could well be transmitted directly through the long circuit, a local voltaic battery and magnet are employed to do the work; and they are brought into action by means of a small electro-magnet, surrounded by a great number of convolutions of very fine wire, that may be actuated by the feeble intensity current transmitted by the communicating wire. This kind of telegraph is extensively used in the United States and on the continent, and it is coming into general use in this country.

In the modification of Professor Morse's instruments, as used by the Electric Telegraph Company, the marks on the paper are made by the agency of electro-chemical decomposition, and not by mechanical pressure. The application of electro-chemical decomposition to telegraphic purposes was first adopted by Mr. Davy in 1838. His plan was to moisten paper in a diluted solution of nitric acid and prussiate of potass, and to send a voltaic current from the positive pole of the battery through a steel wire pressing on the paper. By the action of electricity, the oxygen of the acid attacks the steel wire, and a deposition of iron is made on the paper, and it is converted into Prussian blue by the prussiate of potass. The arrangements of Mr. Davy's recording telegraph need not be described, as they were never made practically available; but his system of marking paper by electro-chemical agency has been successfully applied to other telegraphs.

In 1846, Mr. Bain contrived a modification of Professor Morse's system, in which the marks are made by Mr. Davy's process. The transmission of symbols in this telegraph of Mr. Bain's is not effected by a key moved by hand, but metallic contact is made and broken by mechanical means. Apertures are punched in a strip of paper, to correspond with the dots and strokes intended to be impressed on the paper of the receiving *instrument*. The paper message when thus prepared, is passed *rapidly* over the periphery of a metal wheel, and [illegible] wire

spring, connected with a voltaic battery, presses on the paper as it passes along. The spring, by pressing through the holes, touches the wheel, which is connected with the other pole of the battery, and thus completes the voltaic circuit, which is again broken when the spring rests on the insulating paper. Mr. Davy's prepared paper is applied at the receiving station, and the effect of the action of the two corresponding instruments is to transmit dots and strokes, marked in Prussian blue on the paper at the receiving station, agreeing with the smaller and larger holes punched in the strip passed through the transmitting instrument. The annexed diagram represents a piece of the punched paper with the symbols of the word "Bain."

Fig. 112.

The rapidity of transmission by this means exceeds that of any other telegraph. As many as 1,000 letters a minute are said to have been transmitted from London to Manchester; but the time required for punching the paper preparatory to sending a message, is a serious drawback to the general use of the system, and it is consequently not adopted.

The Electric Telegraph Company, when they employ any other instrument than the needle, use that of Professor Morse, with the substitution of electro-chemical marks for those produced by mechanical pressure. This plan, though it is called "Bain's printing telegraph," is, in fact, Morse's telegraph, with Davy's chemical marks, and is distinct from Mr. Bain's invention, the essential part of which was the preparation of the message by mechanical means. The rate at which messages can be transmitted by means of the key with a single communicating wire, is about sixty letters a minute. The transmission, however, requires the utmost attention on the part of the operator, who cannot continue to transmit at that rate for a continuance.

Among the early inventions of recording telegraphs were some that printed letters from metal types. Professor Wheatstone and Mr. Bain disputed for the honour of being the inventor of the first printing electric telegraph; but their instruments did not attain such a degree of perfection as to render them practically useful. Mr. House, of America, and subsequently Mr. Brett, have, however, succeeded in producing printing telegraphs which work effectively through long circuits. The mechanism is [illegible] *plicated, but* [illegible] *inciple* on which the action depends [illegible]

easily understood. A small wheel, that revolves by the agency of electro-magnetism, carries on its circumference metal types of each letter of the alphabet, which are inked as the wheel turns round by rubbing on the surface of a small inking roller. At one part of the circumference of the type-wheel there is a ribbon of paper close to the types, and by the pressure of the paper against the wheel the letter that is opposite to it is printed. The movement of the type-wheel is regulated by the operator at the transmitting instrument, who, by bringing an index to point on the dial of his instrument to the letter required, it at the same time causes the type-wheel to move round, so as to bring a corresponding letter opposite the paper. A local electro-magnet is then put in action; by which means the drum on which the paper rests is pressed against the type, and the letter is printed. As each letter is thus printed, the strip of paper is moved onward about a quarter of an inch to leave a clear space for the next.

The action of the printing telegraph is rather slow; but it is worked with a single wire. We have not seen it working faster than at the rate of forty letters a minute; but we are informed that it can print sixty letters in that time. One peculiar advantage of Mr. Brett's arrangement is, that the type-wheel is placed in correct position at the end of each transmission; so that if by mistake an error is committed, by printing one letter instead of another, that error is not continued to the next letter, for the type-wheel is adjusted to start from zero before the next movement of the index. All preceding printing telegraphs were liable to perpetuate errors whenever a single one had been committed.

[illegible] copying telegraph, of which the author of this work is [illegible] inventor, transmits copies of the hand-writing of corre[illegible]. The advantages of this mode of transmission are, [illegible] communications may be authenticated by the recognized [illegible] the parties by whom they are sent, and as the [illegible] is traced from the original message, there can [illegible] transmission; for every letter and mark made [illegible] transferred exactly to the other instrument, [illegible]

[illegible] mode of marking the paper, invented by [illegible] in the copying process. The writing is [illegible] in a solution of prussiate of potass and [illegible] of steel wire serving for the pen. The [illegible] cylinder about six inches in diameter, [illegible] with the copper end of the voltaic [illegible] is carried slowly along by a screw [illegible] By this arrangement, when the voltaic

current passes uninterruptedly from the wire through the paper to the cylinder which is connected with the zinc end of the battery, lines are drawn upon it at the same distance apart as the threads of the screw that carry the point. These lines are in fact but one continuous spiral line, commencing at one end of the cylinder and ending at the other.

The communication to be transmitted is written on tin foil, with a pen dipped in varnish. Thin sealing wax varnish, made by dissolving sealing wax in spirits of wine, answers the purpose best, as it dries very quickly. The letters thus written form on the conducting metal surface a number of non-conducting marks, sufficient to interrupt the electric current, though the deposit of resinous matter is so slight as not to be perceptible by the touch.

The message on tin foil is fixed round a cylinder at the transmitting instrument, which instrument is a counterpart in its mechanical arrangements of the receiving one, and either of them may be used to transmit and receive messages. A metal style in connection with the voltaic battery presses on the tin foil, and it is carried along by an endless screw as the cylinder revolves, exactly in the same manner as the steel wire that draws lines on the paper of the receiving instrument. The varnish writing, when it interposes between the style and the tin foil, stops the electric current; consequently, at every part where the electric current is stopped by the varnish at one instrument, the steel wire ceases to make marks on the paper at the other station. Both instruments are so regulated that the cylinders rotate exactly together, therefore the successive breaks of the electric current by the varnish-letters cause corresponding gaps to be made in the lines on the paper; and the succession of

Fig. 113.

these lines, with their successive gaps where the letters occur, produces on the *paper of the receiving instrument the ex-* *forms of the letters.* The letters appear of a white or

colour on a ground of blue lines, there being about nine or ten lines drawn by the wire to make one line of writing. In the diagram, A shows the writing on tin foil, from which the copy is made in the form shown at B.

By a recent improvement in the mode of writing the messages, the letters are transmitted impressed in dark characters on a pale or white ground, as in ordinary writing. The tin foil is in this case first prepared with a thin coating of varnish, and the ink is composed of coloured caustic soda. After the message is written, a wet sponge readily clears away the varnish from the letters, and leaves the writing metallic on a non-conducting surface of varnish. By this means marks are made on the paper only where the style of the transmitting instrument presses on the letters. If we suppose the strip B to be the tin foil message prepared in this manner, then the upper strip A would represent the writing transmitted.

It is essential to the correct working of the instruments that the cylinders should rotate exactly together. This synchronous movement of the two instruments is effected by means of regulating electro-magnets, aided by a "guide line" on the transmitting cylinder.

The moving power of each instrument is gravity, accelerated motion being prevented by a rapidly revolving fan, which produces a very steady movement of the cylinder. The speed may thus be very easily varied by adding or by taking off weight. The "guide line" consists simply of a strip of paper pasted across the tin foil at a right angle, as shown at C. That strip of paper effectually stops the electric current, and leaves a gap of equal breadth in each line drawn on the prepared paper of the receiving instrument. If the receiving instrument be moving at exactly the same speed as the transmitting one, these gaps in each line will be in the same relative positions, and will fall under each other on the receiving cylinder, making a broad white stripe corresponding with the strip of paper on the transmitting cylinder. But if the receiving cylinder be moving faster than the other, the gaps in the lines will not fall under one another, but every one will be farther towards the right hand. By noticing the position of these gaps on the paper, it may be seen exactly how much faster one instrument is going than the other, and weight may be taken off the receiving instrument until the gaps form a continuous stripe. In this manner the two instruments may be regulated to move together. It is immaterial at what distance apart they are; for if they be in the same room, or two hundred miles from each other, the same plan of adjustment must be adopted.

Supposing the mechanism of the instruments to be very good, and that there were no irregularities on the surfaces of the cylinders, the plan of regulating by means of the guide line alone would be sufficient for the copying process. Legible writing may, indeed, be obtained in that manner, but not with sufficient accuracy and certainty to be depended on in ordinary working operations. To secure the requisite degree of accuracy and certainty, an electro-magnetic regulator is used. This may be brought into action by means of a second communicating wire or by local action altogether; in the latter case a single wire only is required to work the copying telegraph. When two wires are employed, one of them is used for the electro-magnet that regulates the instruments, the other for transmitting the current that marks the paper by electro-chemical decomposition. The annexed diagram will assist in explaining the mode of regulating the instruments when a separate wire is used for that purpose.

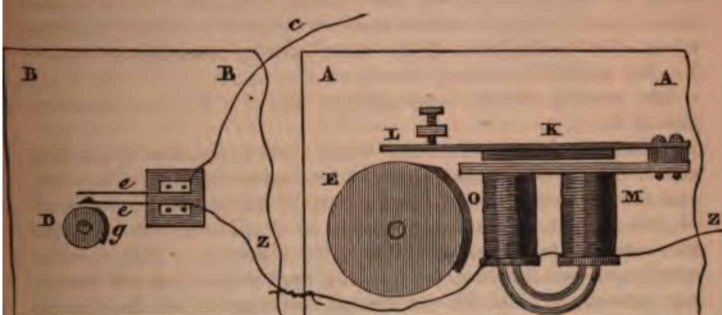


Fig. 114.

A side view only of the two instruments is given, without their stands or other mechanism than that which appears on the outside of each; the trains of wheels propelled by the weights being contained within the cheeks A A and B B, and the cylinders being on the opposite sides. The wheel D is fixed to the projecting arbor of a fast-moving wheel next to the fan, and it makes twelve revolutions to one of the cylinder. Two springs *e e*, insulated from the instruments by being mounted on wood, are connected by wires *c* Z to the voltaic battery, and to the electro-magnet M on the other instrument. The other end of the coil of wire round the electro-magnet is connected with the voltaic battery, so that when the two springs e e *circuit of the battery* is completed, and the elect

instantly brought into action. This occurs once every revolution of the wheel D, by the projecting part *g* pressing the two springs together. The wheel E on the instrument A is fixed on to the arbor of a wheel corresponding with that of D, and likewise makes twelve revolutions to one revolution of the cylinder.

The keeper K of the electro-magnet has an arm or lever L added to it, which reaches to the circumference of the wheel E, and, when the keeper is attracted by the magnet, rubs against a projecting part of the circumference O, and thus operates as a break to check the motion of the instrument. In regulating the instruments to rotate synchronously by these means, a heavier weight is put on A than on B, to cause it to rotate considerably faster than the other when the break is not applied. But when both instruments are set in motion, the lever being pulled down, each time that the springs are pressed together by the wheel D, the break is thus put in operation just sufficiently to make the movements of the two instruments correspond. By this arrangement it will be observed that one instrument regulates the other; and it has it under such complete control, that if the speed of B be diminished, the movement of A will be retarded by the longer continued action of the break, and be made to rotate equally slowly, and even to stop by stopping the motion of B.

When the instruments are worked at a distance from each other, the electro-magnet M is put into action by a local battery, and the contact is made and broken by an intermediate small electro-magnet, as in Mr. Morse's telegraph. In that manner the copying telegraph has transmitted messages with perfect accuracy from Brighton to London, and with a pair of instruments recently made for the French Government, copies of writing were transmitted along the wires from Paris to Nantes, a distance of 300 miles.

When a single communicating wire only is used, the instruments may be regulated independently of each other by means of pendulums. Clock-movements, with pendulums that beat four times in a second, are employed at each instrument. These pendulums at every vibration strike against springs, at each contact with which the electro-magnets which regulate the instruments are brought into action.

The arrangement of the mode of making and breaking contact by the pendulum will be easily understood by the diagram. The pendulum D is connected by the wire *c* to the electro-magnet M. The springs *s s'* are connected with the voltaic battery V, from which a wire *z* connects with the other end of the coil of the electro-magnet. It will be evident, therefore, that when the

end of the pendulum vibrates against $s\, s'$, the voltaic circuit is completed through the magnet, which is brought into action in regulating the instruments as rapidly as the pendulum beats. Each instrument has its regulating magnet and pendulum, and

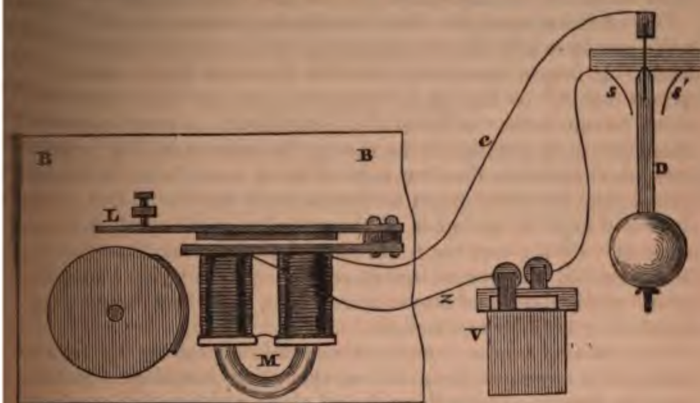


Fig. 115.

the regulation of each is thus effected independently, without requiring a second wire.

The guide line serves to indicate with the greatest accuracy whether the pendulums at two corresponding stations are beating together; for if one be vibrating faster than the other, the guide line on the paper will be slanting instead of perpendicular; and by means of an adjusting screw to raise or lower the pendulum bob, the two may be readily adjusted to beat together. In this manner a variation of even the thousandth part of a second may be observed and corrected. By improvements recently made in the plan of working the instruments on a connected system, they may be regulated when using a single wire without the intervention of pendulums.

It may probably be supposed, because the metal style has to pass over each line of writing nine or ten times to complete it, that the copying process must be necessarily slow; but it is, on the contrary, the quickest mode of transmission yet invented, with the exception of Mr. Bain's. A cylinder six inches in diameter will hold a length of paper on which one hundred letters of the alphabet may be written in a line. When the instruments are working at their ordinary speed, the cylinder revo[illegible] *times in a minute;* and allowing ten revolutions [illegible]

each line of writing, the rate of transmission is three hundred letters in a minute. Much greater speed than that has been obtained ; and there is, indeed, no limit to the rapidity of transmission other than the diminishing strength of the mark on the paper when the decomposition is extended over a larger surface.

One of the advantages which the copying process also possesses is the means it affords of maintaining the secrecy of correspondence. It is now customary for those who wish their communications not to be known, to transmit messages in cypher, by which certain letters or figures have significations given to them which are only intelligible to the parties corresponding. This plan has the serious disadvantage of being very liable to error, because the clerks engaged in transmitting such a message are purposely kept in ignorance of the meaning of the symbols they transmit. By the copying telegraph, whatever symbols are made on the tin foil are transmitted as accurately as if written in full, for no manipulation whatever is required, the effect being produced altogether by mechanism.

There is also a special mode of maintaining secrecy by transmitting the messages impressed on the paper invisibly. If the paper be moistened with diluted acid alone, the iron is deposited on the paper, but no mark whatever is visible, and the paper remains blank until it is brushed over with a solution of prussiate of potash, which instantly renders it legible. In this manner messages may be transmitted without any one seeing the contents ; that part where the name and address are written being alone rendered legible till the message is delivered to the person for whom it is intended.

The author trusts he shall be excused for having described thus fully his invention of the copying telegraph. It is very probable that he attaches more importance to it than those who are not so specially interested may think that it deserves ; but he has received the assurance of some scientific gentlemen who have been the longest and the most successfully engaged in such undertakings, that the copying of writing is the *beau ideal* of telegraphic communication, and that sooner or later it must supersede all other means of corresponding by electric telegraph.

CHAPTER IV.

ELECTRO-METALLURGY.

Competing claims to the discovery—Deposition of metals from their solutions—Dependence of the process on secondary results—Rationale of the deposition of metals from their solutions—Apparent anomaly of deposition in a single cell—Formation of moulds—Copying medals—Reduplication of copper-plate engravings—Glyphography—Electro-plating and gilding.

THE important application of electricity to working in metals is of even more recent date than the invention of the electric telegraph. The fact that metals could be "revived" from their solutions by means of electricity was, indeed, known at the beginning of the present century. In 1805 Brugnatelli gilded a large silver medal, by connecting it with the negative pole of a voltaic battery and then immersing it in a solution of ammoniuret of gold; but, strange as we now think it, the practical use to which this peculiar action of electricity might be applied did not occur to him. Mr. Spencer of Liverpool claims to be the first who discovered that the deposition of metals by electrical agency might be rendered useful in the arts. He states, that when experimenting in 1837 with a Daniell's battery, he used a penny instead of a plain piece of copper for one of the poles, and that on removing the wire which connected the penny with the battery, he pulled off a portion of the deposited copper, which he found to be impressed with a counterpart of the head and letters of the coin. Even this did not suggest to Mr. Spencer any useful application, until he accidentally dropped some varnish on a piece of copper similarly connected with the negative pole, and he observed that no deposition of copper took place on those parts covered by the varnish. It then occurred to him that by covering a sheet of copper with varnish or wax, and cutting a design through it so as to lay bare the metal, the copper would be deposited from the solution of sulphate of copper in the lines of the design cut through the wax, and would adhere to the surface of the plate, producing the figure in relief.

The experiments by Mr. Spencer were not made known until 1839, after Professor Jacobi of St. Petersburg was an[illegible] to have made a similar discovery. Indeed, before th[illegible]

[illegible]

[illegible] indicated in the accompanying diagram [illegible] the process is conducted when the decompo[illegible] a cell apart from the voltaic battery. The [illegible] b contains a saturated solution of sulphate of [illegible] A strip of metal f, with a binding screw [illegible] to make attachment to the voltaic battery, serves as a support from which to suspend the objects to be coated with copper. A plate of copper e, which is connected with the positive pole of the battery, serves the double purpose of transmitting the voltaic action to the fluid in which it is immersed, and

* Page 184.

keeping up the supply of sulphate of copper by its combination with the sulphur and oxygen of the decomposed solution, the deposition of the metal on the medals proceeds. In the figure three medals are represented suspended by wires from *f*, and the wire *d*, which is attached to the copper plate of the voltaic battery *a*, is connected with the plate *e*, and the zinc of the battery is connected with the medals by the wire *c*. An

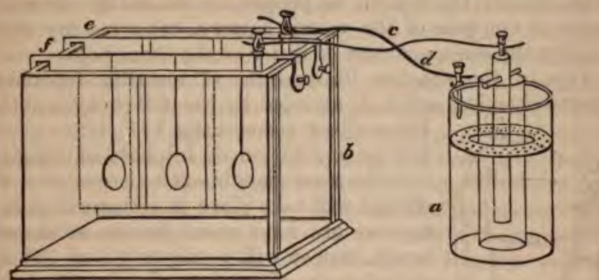


Fig. 116.

electric current is thus established from the plate of copper *e*, through the sulphate of copper solution to the medals. The fluid is thus decomposed, and the oxygen of the water is directed to the plate of copper *e*, and the hydrogen is directed to the medals. Neither gas is, however, liberated in a gaseous form. The hydrogen, the instant that it is liberated from its association with oxygen of the water, combines with an equal quantity of the oxygen that holds the copper in solution, to form the sulphate of that metal, and the copper is deposited in a metallic state upon the medal. The oxygen liberated at plate *e*, combines with a particle of copper equivalent to that which is deposited on the medal, and that being immediately dissolved in the fluid, maintains it in the state of a saturated solution of copper.

The deposition of the metal from its solution is the result of a variety of rather complicated chemical actions. The strong affinity of oxygen for the hydrogen, with which it was combined to form water, is first overcome by the influence of the electric force. The oxygen, liberated at the plate *e*, immediately enters into combination with the sulphur in the solution to form a fresh particle of sulphuric acid; the hydrogen, freed from its combination with oxygen, is transferred to the medals, and its affinity for oxygen being greater than that subsisting between the oxygen and the copper held in solution, the hydrogen re-enters into combination with oxygen and forms a fresh particle of water, whilst the copper is set free in its metallic state and is

deposited. In all the processes of electro-metallurgy, whether they consist in the depositions of copper or of other metals from their solutions, the same chemical actions and reactions take place; the hydrogen in every case effects the deposition of the metal by combining with the oxygen which holds the metal in solution at one pole of the battery, after having been separated from an equal particle of oxygen at the positive pole. There is, consequently, throughout the process a continual decomposition of water at one pole of the voltaic battery, and a recomposition of exactly the same quantity of water at the other pole.

One of the simplest illustrations of metallic deposition by electro-chemical action is afforded by the following experiment.

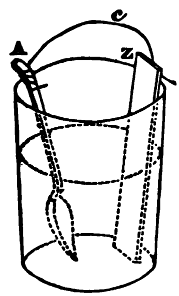


Fig. 117.

Put a silver spoon A (fig. 117), into a glass containing a solution of sulphate of copper, and into the same glass insert a piece of zinc, z. No change will take place in either metal so long as they are kept apart, but as soon as they touch, copper will be deposited on the spoon, and if it be allowed to remain, the part immersed will be completely coated with copper, which will adhere so firmly that mere rubbing alone will not remove it. The same effect takes place, if instead of bringing the metals into contact in the solution, they are connected externally by the wire *c*.

The foregoing experiment represents the electrotype process as carried on in a single cell, the metal surface whereon the copper is deposited then forming the conducting-plate of the voltaic arrangement by which the electricity is generated. It must be observed that, in this single-cell arrangement, the deposition takes place on the conducting-plate; whereas, when the operation is conducted in a separate cell, it is on the plate connected with the zinc that the deposition occurs. In order to explain this apparent anomaly, let it be remembered that the metal is always deposited from its solution on the surface *into* which the electric current enters, and that that is the negative pole of the battery. The electricity excited by the zinc passes through the fluid and enters into the conducting-plate; therefore, when the deposition takes place in the same cell, the metal is deposited on that surface; but when the electric current is transmitted through a wire into a separate cell, it then proceeds *from* the conducting-plate, that wire becomes the positive pole of the battery, and when introduced into the decomposing cell, the electric current passes from it to the metal surface connected with the other, or *negative pole*, on which accordingly the deposit takes place.

Having, we trust, made the *rationale* of the electrotype process intelligible, it is only necessary to give a general explanation of the modes of operating. Those who desire to pursue the art practically will do well to consult the able and compendious treatises on this subject by Mr. Napier, Mr. Smee, and by Mr. C. V. Walker.

The first application of the electrotype process was to the copying of ancient coins and medals, and that continues to be the principal use to which it is applied by amateurs. To obtain a fac-simile of a medal, it is necessary in the first place to make a mould, to serve as a matrix for the copper to be deposited upon. This may be done, when circumstances will permit, by obtaining an electrotype directly from the surface of the medal. To do this, the surface whereon the deposition is to take place must be well cleaned, and afterwards smeared over with a minute quantity of sweet oil, or with black lead, which is requisite to prevent the deposited copper from adhering. The thinnest possible film of oil should be allowed to remain, for even after the medal has been rubbed with dry cotton-wool, sufficient will adhere to effect separation from the deposit. It is evident that only one face of the medal can be copied at a time, therefore the side not to be operated on must be protected by a covering of wax. The preparation of the medal is completed by twisting a fine wire round the edge for the purpose of suspending it in the copper solution, and of connecting it with a piece of amalgamated zinc.

Fig. 118.

The decomposing apparatus may consist of a large preserve jar (fig. 118), to hold the solution of sulphate of copper, and a porous vessel *c* placed within the jar to contain the zinc. Fill the porous vessel to within a few inches of the top with a mixture of sulphuric acid and water, in the proportion of one of acid to twenty-four of water, taking care that the solution in the jar, and the acidulated water in the porous vessel, are nearly on the same level. The medal *e* suspended by the wire is then immersed in the jar, and is connected with the zinc in the porous vessel by the wire *a b*, as shown in the diagram.

This arrangement may be considered as equivalent to a single cell of a Daniell's battery, in which the medal represents the conducting-plate. The electric action is established as soon as the zinc and the copper are immersed; the deposition of the copper on the medal immediately begins, and it is continued *long as the action* is maintained. In twenty-four hours

deposited. In all the [illegible] of a card, which is
they consist in the deposit[illegible] may be easily separated
their solutions, the same [illegible] exact counterpart of it,
place ; the hydrogen in [illegible] of course presented a
metal by combining with [illegible] to be treated exactly
solution at one pole of the [illegible] deposited on it, so that
from an equal particle of [illegible] fac-simile of the medal
consequently, throughout [illegible] with the original. A
water at one pole of the [illegible] to take many copies.
exactly the same quantity [illegible] directly on the surface

One of the simplest [illegible] taken by other means ;
electro-chemical action is [illegible] ancient coins, the surfaces

Fig. 117.

Put a [illegible] mode being adopted, and
taining [illegible] be found. One of the
into the [illegible] original in fusible metal.
change [illegible] small wooden tray, and
as the [illegible] coin is suddenly pressed
touch, [illegible] "sets." The fusible metal
and if [illegible] tin, lead, and bismuth,
mersed [illegible] to one each of the former
which [illegible] below that of boiling
alone [illegible] for removing the moulds
takes [illegible] adhere.
into [illegible] percha, are frequently em-
nected [illegible] for large objects. When

The foregoing exper[illegible] to cover their surfaces
as carried on in a single [illegible] conductors of electricity.
is deposited then form[illegible] impart a sufficiently good
arrangement by which [illegible] are otherwise incapable of
observed that, in this [illegible] great facility in extend-
takes place on the com[illegible] leaves, lace, and even
tion is conducted in a [illegible] thin protecting film of metal,
with the zinc that the [illegible] and durably.
this apparent anomaly [illegible] electrotype process is the
always deposited from [illegible] which are thus rendered
electric current enters [illegible] quickly distributes the heat
battery. The electric [illegible] them from breaking, as
fluid and enters into [illegible] expansion. The surface of
deposition takes place [illegible] by the fumes of hydro-
that surface ; but when [illegible] black leaded, to form an
a wire into a separate [illegible] for the metallic deposit.
plate, that wire be[illegible] of the art of electrotyping
when introduced into [illegible] engravings. A cast is first made
passes from it to the [illegible], in the same manner as
negative pole, on wh[illegible] In such a cast all the lines are

... is requisite, therefore, to make a second deposit on ... to obtain a fac-simile with the lines engraved. ... shows more clearly the beauty of the electrotype pro... these transfers of copper-plate engravings. The finest ... most faithfully copied, and it is impossible to distinguish ... taken from the electrotype from the proof impression ... original.

... at one time expected that this mode of multiplying ... plate engravings would supersede engraving on steel ...; but it has been found in practice, that the copper de... does not possess sufficient hardness to resist the wear and ... of copper-plate printing. This objection may, however, be ...; and there were displayed in the Great Exhibition ... of copper deposited by electro-chemical decomposition, ... appeared to possess the firmness of hammered plates.

A very successful application of electro-metallurgy to the fine ... is the process called glyphography. It consists in depositing on a plate of copper a design in relief, that may be printed from by the letter-press. The surface of the copper plate is coated with wax, through which the design is cut sufficiently deep to expose the metal. This plate is then electrotyped, and copper is deposited in all the lines cut through the coating. By this means there is left on the plate, when the wax is removed, a perfect copy of the design in relief, so bold as to be printed from. This is, in fact, the original process invented by Mr. Spencer. The advantage it possesses over wood-engraving is in the facility of shading by "cross hatching," as it is termed, so as to resemble an etching on copper plate.

The success or failure of the electrotype process depends very much on the preparation of the copper solution, and on the strength of the voltaic battery. A perfectly saturated solution is not so well adapted for the purpose as such a solution diluted with one-fourth part of water. To prevent it from becoming too weak by the deposition of metallic copper, some crystals of the sulphate are added during the process.

Mr. Smee determined the laws that regulate the deposition of metals in different states. The strength of the battery, in relation to the strength of the solution, causes the metals to be deposited either as a black powder, in a crystalline form, or as a flexible plate. The metals are deposited as a black powder when the current of electricity is so strong that hydrogen is evolved from the medal or negative plate in the decomposition cell. The crystalline state occurs when there is no evolution of gas, and no tendency thereto. The regular deposit takes place wh... *electric current is stronger* in relation to the solution ...

the last case, but is not sufficiently strong to cause the evolution of gas.

The art of electro-metallurgy has been more extensively practised in plating and gilding than in any other way. To appreciate the advantage of the process of electro-plating, it is requisite that the mode of manufacturing plated articles by the ordinary means should be understood. A thick plate of silver is attached to an ingot of copper, and the metals, after being heated, are passed through rollers, until they are reduced into a thin sheet of plated copper, the silver being equally spread over the surface. The plated copper is then cut into pieces, punched into the required forms, and soldered together; the interior being filled with melted lead. Such articles cannot be ornamented by engraving or chasing, but by milling and punching only. When the process of electro-plating is used, the articles may be cast, or put together in any convenient method, and the most elaborate designs may be worked in metal, which, on being afterwards coated with the purest silver, present an appearance in every respect equal to the finest works in the solid metal.

The operations for electro-plating differ in several particulars from the ordinary process of the electrotype. The single-cell arrangement which has been described, is inapplicable to the deposition of one metal upon another of a different kind. The plan of having a separate battery, with two or more combinations of plates, is indeed necessary even in the deposition of copper upon copper, when the operation is conducted on a large scale, and the electric current has to pass through a considerable resisting medium.

To effect the deposition of silver or gold upon metals that are oxidizable, a peculiar kind of menstruum is required; for if the silver be held in solution by an acid that will attack the baser metal, no electro-chemical deposition of metallic silver can be effected. The menstruum that is found most suitable for the purpose, is a solution of cyanide of potassium. There are various modes of preparing the solution and of dissolving the silver, but the cheapest and best, as recommended by Mr. Napier from practical experience, is to dissolve the silver in a solution of cyanide of potassium, by the action of a voltaic battery. The proportions mentioned are for operation on a large manufacturing scale, but the quantities may be reduced according to the requirements of the amateur. The directions he gives are as follow:—"Dissolve 123 ounces of cyanide of *potassium* in 100 gallons of water; get one or two flat porous *vessels,* and place them in this solution to within half an inch of

the mouth, and fill them to the same height with the solution; in these porous vessels place small plates or sheets of iron or copper, and connect them with a zinc terminal of a battery; in the large solution place a sheet or sheets of silver connected with the copper terminal of the battery. This arrangement being made at night, and the power employed being two of Wollaston's batteries of five pairs of plates, the zincs seven inches square, it will be found in the morning that there will be dissolved from 60 to 80 ounces of silver from the sheets. The solution is now ready for use." The strength of the solution recommended is that of one ounce of silver to the gallon.

During the process of plating, the sheets of silver immersed in the solution gradually dissolve as the metal is deposited, and by this means the solution is maintained at the same strength.

In preparing articles for plating, they must be completely freed from grease by washing in an alkaline ley, and dipped into very diluted nitric acid to remove any traces of oxide. The object is then suspended in the decomposing trough and connected with the negative pole of the battery, the positive pole being placed in connection with a sheet of silver in the solution. Silver is immediately deposited, and the plating process proceeds as long as the object continues immersed. An ounce and a-half of silver to one square foot of surface gives an excellent plating.

The articles when taken out of the solution are white, the silver being afterwards polished on the parts required to be bright. A bright deposit may, however, be made by adding a little sulphuret of carbon to the solution. When a thin coating of silver is deposited on a bright surface, the silver is also bright. In order to obtain a coating of dead silver on a medal, it should have a thin film of copper deposited over its surface before it is immersed in the silver solution, by which means the silver, even when very thin, will be white.

In operating on a large scale, the decomposing trough is upwards of two yards long, one yard deep, and one yard wide, and contains about 250 gallons of the solution. At Messrs. Elkington's establishment at Birmingham, several of these troughs are in continual use. The silver plates in a single trough expose a surface of nearly thirty square feet, and the articles to be plated are suspended from metal rods that are connected with the positive pole of the battery. The voltaic batteries used by Messrs. Elkington generate large quantities of electricity of low intensity. When we inspected their manufactory, the deposition of each trough was effected by batteries, the zincs of which were three feet long b

inches wide. Mr. Napier, however, recommends batteries with smaller plates, with several combined in a series, to increase the intensity of the electric current.

The operation of electro-gilding very closely resembles that of electro-plating. The gold solution may be prepared by dissolving gold in a solution of cyanide of potassium in the same manner as the silver, but the liquid should be heated. The strength of the gold solution need not exceed half an ounce of gold to the gallon, and a sufficiently thick coating of the metal is deposited in two or three minutes. Voltaic batteries of three or four pairs of plates are generally employed for electro-gilding; but if the solution be heated to nearly the boiling point, a single pair will answer the purpose, for the hotter the solution the less the battery-power required.

The method of gilding, before the introduction of the electro-chemical process, was extremely injurious to health. The gold was converted into a thin amalgam with mercury, which was brushed over the surface of the article to be gilt. The gold thus combined with the baser metal, and by a subsequent exposure to a strong heat, the mercury was dissipated and the gold remained. The fumes of mercury disengaged during this operation produced most pernicious effects notwithstanding the care taken to prevent it; so much so, indeed, that the average lives of the workmen engaged in gilding by mercury do not exceed thirty-five years. Electro-gilding is also prejudicial to health, though not to the same extent, and the operation should be conducted in a lofty well-ventilated room.

CHAPTER V.

ELECTRIC CLOCKS.

First application of electricity to indicate time—Bain's self-acting electric clock—Means of making and breaking contact—Application of mechanical power—The earth battery—Shepherd's electro-magnetic clock—Independence of the pendulum, and its advantages—Instantaneous indication of Greenwich time at distant places.

The claim to the invention of electric clocks has been disputed by Professor Wheatstone and by Mr. Bain; but whatever claim Professor Wheatstone may have to be the original designer of such application of electric force, to Mr. Bain is unquestionably due the merit of having brought it into practical operation.

In 1841, Mr. Bain, in conjunction with Mr. Barwise, obtained a patent for the application of electricity to the regulation and movement of clocks. The invention at that time specified had for its principal object the movement of several clocks by currents of electricity, transmitted at regular intervals by the agency of a clock of the ordinary construction. The advantage proposed to be gained was, to make any number of clock-dials in a large establishment indicate exact time with one well-made clock, without requiring any impelling mechanical power. By a subsequent improvement of the invention, each clock was made to move independently by electricity, without any assisting clock to regulate the transmission of the electric current. The arrangement by which the independent regulated movement is obtained will be understood by the annexed figure.

The bob A, of the pendulum A B, consists of a hollow coil of covered copper wire. A hollow brass tube C C, about two inches in diameter, passes through the coil, there being sufficient space left for the coil to move to and fro without touching. Within the hollow tube, and on each side of it, are placed permanent bar magnets, with their similar poles presented towards each other at a distance of about four inches apart. For example, the magnets within the tube on the right hand have their north poles presented to the coil, and those on the left hand have also their north poles presented to it. When an electric current passes through the coil it becomes instantly magnetic; the end tow

... having a south polarity, and that ... The coil is consequently immediately attracted towards the ... and is repelled by the magnets ... the left, as the pendulum swings ... that direction. Before arriving ... the end of its vibration, the connection with the voltaic battery is broken by the action of the pendulum itself, the magnetic property ... the coil instantly ceases, and it descends by the force of gravity. In ascending the other arc of its vibration, contact is again made with the battery, and the electric current is sent through the coil, but in the reverse direction: so that the left hand end of the coil has south polarity given to it, and the right becomes the north pole. By this ... is impelled towards the left, and ... are thus maintained for an inde-

... with the wires of the voltaic ... action of the electric current, a ... side to side by the pendulum. ... ends of the hollow coil are ... A cross piece of wood fixed to ... upon the light moveable frame ... being gold wires. Inlaid in ... of gold, connected by wires to ... pendulum vibrates towards the ... towards the right hand, so ... rest on the studs: by this ... the voltaic battery, and an ... through the coil A. On the ... the moveable frame is ... electric current is reversed. ... is changed at each vibration

... power of a weight or spring ... wheels, and the use of the ... the motion; but in Mr. ... of the pendulum propels the ... connected with. The mode by

which the vibrations of the pendulum are applied to propel the hands will be readily understood on inspection of fig. 120.

An electro-magnet, A, is fixed on the top of the clock, and an electric current is sent through the coil on each vibration of the pendulum. Each time that the electro-magnet is put in action by these transmissions of electricity, the keeper B, to which the light jointed click-lever D is attached, is attracted, and falls into a tooth of the ratchet-wheel E. When the connection with the battery is broken, on the fall of the pendulum, the lever is forced back by the spring at B, and thus advances the wheel the space of one tooth. A small spring at the bottom, L, keeps the wheel steady, and prevents it from turning back during the next vibration; and by this arrangement, the ratchet-wheel is advanced one tooth by two swings of the pendulum. Thus, when the wheel contains thirty teeth, and the pendulum vibrates once a second, the wheel will make one complete revolution every minute. That wheel will therefore constitute the seconds wheel of the clock, and the minute and hour hands may be moved by it, in the same manner as in ordinary clocks.

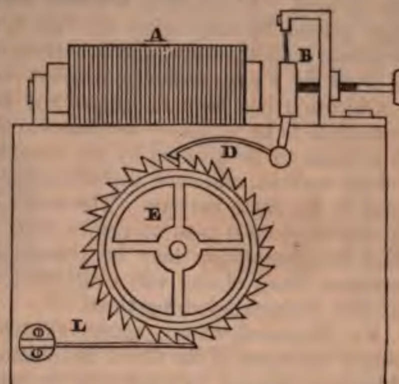


Fig. 120.

The voltaic power employed by Mr. Bain in working these clocks, consists of a large plate of zinc, and a quantity of coke buried in moist ground.

Mr. Bain was the first who directed attention to the use that may be made of the moisture of the earth in exciting a very steady current of voltaic electricity. In his earlier experiments he employed a large plate of zinc and a corresponding plate of copper; but it was afterwards found that coke or charcoal, among which copper wires were introduced to act as conductors, answered the purpose better, because a larger surface is thus exposed to contact with the moisture. On making connection between the coke and the zinc, a current of electricity is established, which, though of very feeble intensity, is sufficiently powerful to keep the pendulum of the electric clock in motion.

deposited. In all the processes of electro-metallurgy, whether they consist in the depositions of copper or of other metals from their solutions, the same chemical actions and reactions take place; the hydrogen in every case effects the deposition of the metal by combining with the oxygen which holds the metal in solution at one pole of the battery, after having been separated from an equal particle of oxygen at the positive pole. There is, consequently, throughout the process a continual decomposition of water at one pole of the voltaic battery, and a recomposition of exactly the same quantity of water at the other pole.

One of the simplest illustrations of metallic deposition by electro-chemical action is afforded by the following experiment.

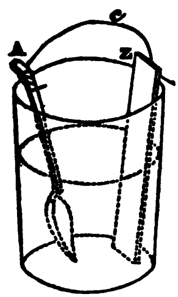


Fig. 117.

Put a silver spoon A (fig. 117), into a glass containing a solution of sulphate of copper, and into the same glass insert a piece of zinc, Z. No change will take place in either metal so long as they are kept apart, but as soon as they touch, copper will be deposited on the spoon, and if it be allowed to remain, the part immersed will be completely coated with copper, which will adhere so firmly that mere rubbing alone will not remove it. The same effect takes place, if instead of bringing the metals into contact in the solution, they are connected externally by the wire *c*.

The foregoing experiment represents the electrotype process as carried on in a single cell, the metal surface whereon the copper is deposited then forming the conducting-plate of the voltaic arrangement by which the electricity is generated. It must be observed that, in this single-cell arrangement, the deposition takes place on the conducting-plate; whereas, when the operation is conducted in a separate cell, it is on the plate connected with the zinc that the deposition occurs. In order to explain this apparent anomaly, let it be remembered that the metal is always deposited from its solution on the surface *into* which the electric current enters, and that that is the negative pole of the battery. The electricity excited by the zinc passes through the fluid and enters into the conducting-plate; therefore, when the deposition takes place in the same cell, the metal is deposited on that surface; but when the electric current is transmitted through a wire into a separate cell, it then proceeds *from* the conducting-plate, that wire becomes the positive pole of the battery, and when introduced into the decomposing cell, the electric current *passes from* it to the metal surface connected with the other, or *negative pole*, on which accordingly the deposit takes place.

Having, we trust, made the *rationale* of the electrotype process intelligible, it is only necessary to give a general explanation of the modes of operating. Those who desire to pursue the art practically will do well to consult the able and compendious treatises on this subject by Mr. Napier, Mr. Smee, and by Mr. C. V. Walker.

The first application of the electrotype process was to the copying of ancient coins and medals, and that continues to be the principal use to which it is applied by amateurs. To obtain a fac-simile of a medal, it is necessary in the first place to make a mould, to serve as a matrix for the copper to be deposited upon. This may be done, when circumstances will permit, by obtaining an electrotype directly from the surface of the medal. To do this, the surface whereon the deposition is to take place must be well cleaned, and afterwards smeared over with a minute quantity of sweet oil, or with black lead, which is requisite to prevent the deposited copper from adhering. The thinnest possible film of oil should be allowed to remain, for even after the medal has been rubbed with dry cotton-wool, sufficient will adhere to effect separation from the deposit. It is evident that only one face of the medal can be copied at a time, therefore the side not to be operated on must be protected by a covering of wax. The preparation of the medal is completed by twisting a fine wire round the edge for the purpose of suspending it in the copper solution, and of connecting it with a piece of amalgamated zinc.

Fig. 118.

The decomposing apparatus may consist of a large preserve jar (fig. 118), to hold the solution of sulphate of copper, and a porous vessel *c* placed within the jar to contain the zinc. Fill the porous vessel to within a few inches of the top with a mixture of sulphuric acid and water, in the proportion of one of acid to twenty-four of water, taking care that the solution in the jar, and the acidulated water in the porous vessel, are nearly on the same level. The medal *e* suspended by the wire is then immersed in the jar, and is connected with the zinc in the porous vessel by the wire *a b*, as shown in the diagram.

This arrangement may be considered as equivalent to a single cell of a Daniell's battery, in which the medal represents the conducting-plate. The electric action is established as soon as the zinc and the copper are immersed; the deposition of the copper on the medal immediately begins, and it is continued as *long as the r* [illegible] is maintained. In twenty-four hours the

deposited copper will be about the thickness of a card, which is quite sufficient. This coating of copper may be easily separated from the medal, and will be found an exact counterpart of it, those parts in relief on the medal being of course presented as sunk in. The mould thus formed is then to be treated exactly as the medal was, and the copper will be deposited on it, so that when removed the electrotype will be a fac-simile of the medal, with the intaglio and relief corresponding with the original. A mould of this kind will, with care, serve to take many copies.

A mould made by depositing the copper directly on the surface is more sharp in its details than moulds taken by other means; but in many cases, especially with ancient coins, the surfaces cannot be cleaned so as to allow of this mode being adopted, and other means of making the moulds must be found. One of the best plans is to make a cast of the original in fusible metal. The metal is melted and poured into a small wooden tray, and when cooled into a semi-fluid state, the coin is suddenly pressed upon it and held down till the metal "sets." The fusible metal is made by melting and mixing together tin, lead, and bismuth, in the proportions of two of the latter to one each of the former metals. This alloy melts at a temperature below that of boiling water, therefore it affords great facility for removing the moulds from the deposits in case they should adhere.

Wax, plaster of Paris, and gutta percha, are frequently employed for making moulds, especially for large objects. When such substances are used, it is necessary to cover their surfaces with black lead, bronze powder, or other conductors of electricity. The discovery that plumbago will impart a sufficiently good conducting surface to objects that are otherwise incapable of receiving metallic deposits, has afforded great facility in extending the electrotype process. Flowers, leaves, lace, and even insects, may be thus coated with a thin protecting film of metal, which preserves their forms accurately and durably.

A recent valuable application of the electrotype process is the [illegible] of glass and earthenware vessels, which are thus rendered [illegible]; for the metallic coating quickly distributes the heat [illegible] over the surface, and prevents them from breaking, as [illegible]erwise would, by unequal expansion. The surface of [illegible] porcelain is first roughened by the fumes of hydro-[illegible], and then varnished and black leaded, to form an [illegible] conducting surface for the metallic deposit.

[illegible] most delicate operations of the art of electrotyping [illegible] copper-plate engravings. A cast is first made [illegible] electro-chemical action, in the same manner as [illegible] from a medal. In such a cast all the lines are

in relief; it is requisite, therefore, to make a second deposit on that surface to obtain a fac-simile with the lines engraved. Nothing shows more clearly the beauty of the electrotype process than these transfers of copper-plate engravings. The finest lines are most faithfully copied, and it is impossible to distinguish a print taken from the electrotype from the proof impression of the original.

It was at one time expected that this mode of multiplying copper-plate engravings would supersede engraving on steel plates; but it has been found in practice, that the copper deposited does not possess sufficient hardness to resist the wear and tear of copper-plate printing. This objection may, however, be overcome; and there were displayed in the Great Exhibition sheets of copper deposited by electro-chemical decomposition, that appeared to possess the firmness of hammered plates.

A very successful application of electro-metallurgy to the fine arts is the process called glyphography. It consists in depositing on a plate of copper a design in relief, that may be printed from by the letter-press. The surface of the copper plate is coated with wax, through which the design is cut sufficiently deep to expose the metal. This plate is then electrotyped, and copper is deposited in all the lines cut through the coating. By this means there is left on the plate, when the wax is removed, a perfect copy of the design in relief, so bold as to be printed from. This is, in fact, the original process invented by Mr. Spencer. The advantage it possesses over wood-engraving is in the facility of shading by "cross hatching," as it is termed, so as to resemble an etching on copper plate.

The success or failure of the electrotype process depends very much on the preparation of the copper solution, and on the strength of the voltaic battery. A perfectly saturated solution is not so well adapted for the purpose as such a solution diluted with one-fourth part of water. To prevent it from becoming too weak by the deposition of metallic copper, some crystals of the sulphate are added during the process.

Mr. Smee determined the laws that regulate the deposition of metals in different states. The strength of the battery, in relation to the strength of the solution, causes the metals to be deposited either as a black powder, in a crystalline form, or as a flexible plate. The metals are deposited as a black powder when the current of electricity is so strong that hydrogen is evolved from the medal or negative plate in the decomposition cell. The crystalline state occurs when there is no evolution of gas, and no tendency thereto. The regular deposit takes place when the electric current is stronger in relation to the solution the-

CHAPTER VI.

MISCELLANEOUS APPLICATIONS OF ELECTRICITY.

The electric light—Electro-magnetic engines—Blasting rocks—Explosion of fire-damp in mines—Sounding the sea—Determining longitudes—Fire alarms—Table-moving—Prospective applications of electricity.

THE ELECTRIC LIGHT.

THE application of electricity to the purposes of illumination was brought prominently into notice about eight years since, and then promised to become a most valuable means of lighting streets.

The electric light proposed to be employed, though introduced as a new discovery, was nothing more than the previously well-known evolution of brilliant luminous rays from charcoal points when exposed to the action of a powerful voltaic battery. The light thus produced almost equals in brilliancy and purity that of the sun; and if means could be found of regulating the action, so as to insure steadiness and certainty, it would prove a most useful source of illumination.

Mr. Stait, when proposing to make the electric light available, invented a voltaic battery, intended to act with great steadiness, and he introduced arrangements for adjusting the charcoal points, which improvements, it was thought, would overcome the difficulty; but though he succeeded in maintaining the light for a short time, it could not be regulated with the steadiness and certainty requisite for practical use.

An ingenious contrivance by Mr. Allman was in the Great Exhibition, of a self-acting adjustment of the charcoal points, so that the distance apart might vary in proportion to the variations in the power of the battery. We have not, however, heard of any practical application of this invention; and we fear it has not been found to overcome the difficulty.

One of the most successful arrangements for maintaining steadiness in the light is one contrived by M. Duboscq of Paris. The two carbons, as they shorten by the action of the voltaic *current*, are brought nearer to each other, and by means of a *spring*, the action of which is regulated by an electro-magnet, *the two* pieces of carbon are adjusted t[illegible] the same

distance apart; the mechanism, however, is rather complicated, and it fails to produce a steady light that can be depended upon without regulation by frequent manipulation.

An important objection to the application of the electric light, in an economical point of view, is the cost of generating the electric force. It has been ascertained by experiment that the expense of maintaining the requisite battery power would considerably exceed that of a quantity of gas that would yield an equivalent amount of light. This objection, though it might prevent the electric light from coming into general use, would not prevent its being applied in many cases where the question of cost is an inferior consideration, could the constancy of the light be depended on.

The impediment to the perfection of the invention occasioned by the cost of the exciting power, will probably be removed by the discovery of some better and cheaper means of exciting voltaic electricity than by the consumption of zinc; and in that case the electric light may become as common a source of artificial illumination as coal-gas is at the present day. Even in the imperfect state in which the invention now remains, the electric light might, with proper care and attention, be applied with great advantage to many lighthouses on the coast.

The use to which the electric light has hitherto been most successfully applied is to give increased effect to scenic displays in theatres. Some most beautiful exhibitions of the electric light have thus been made in which the purity of the light in contrast with that of gas is strikingly shown.

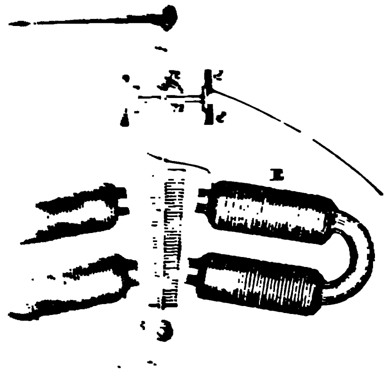
Some investigations, by Professor Wartmann of Geneva, into the applicability of the electric light, tend, indeed, to show that it may be used to advantage more generally than we have, in the existing state of the invention and in the imperfect condition of the voltaic battery, assumed to be practicable.

It is asserted by him that the light emitted from a single pair of charcoal points equals that of 300 large gas burners; and that when a powerful voltaic current is transmitted, the charcoal points may be introduced at several parts of the circuit, and thus distribute the light from separate points of illumination.*

ELECTRO-MAGNETIC ENGINES.

The application of electro-magnetism as a moving power is, like the electric light, also awaiting, for practical purposes, further improvements in the mode of generating voltaic electricity.

* *Philosophical Magazine*, January, 1850.



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electro-magnet D, which consequently becomes magnetic and attracts the lever. The instant before the keeper comes in contact with the magnet, the connections are reversed, by the curved piece *n* shifting the sliding metal from its contact with *e e′* against the opposite studs; and by this means the magnet E comes into action, and the lever is attracted towards it. In this manner the lever may be kept in action for an indefinite time. The alternating movement may be converted into rotary motion by means of a crank, in the ordinary manner.

In some electro-magnetic engines rotary motion is communicated directly to a wheel, without the intervention of a crank, by fixing a number of electro-magnets round the circle of rotation close to the periphery of the wheel, into which numerous pieces of soft iron are inlaid. Each electro-magnet is brought into action in succession by making and breaking contact with the voltaic battery as the wheel revolves; by this means there is a continuous change in the points of attraction round which the wheel is thus made to rotate.

One cause why so little power is obtained by electro-magnetic engines of these constructions is the limited sphere of electro-magnetic attraction. In the arrangement of the vibrating arm, for example, the force with which the keeper is attracted is very feeble until it approaches close to the magnet, when the magnetic action must necessarily cease. With a view to overcome this objection, an arrangement has been contrived in which the attracting power of a hollow coil is employed. A model engine of this kind was placed in the Great Exhibition. Its mode of action will be understood by the annexed section.

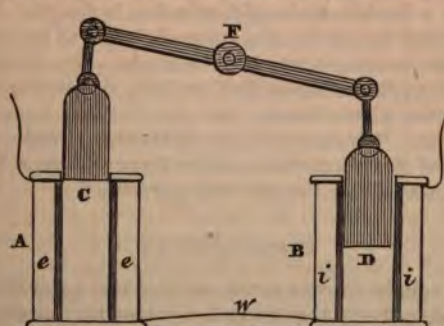

Fig. 125.

Two hollow coils of covered copper wire A B are fixed vertically, the coils being connected together as if they formed the

of an electro-magnet. Inside the coils two hollow cylinders of soft iron *i i* and *e e* are introduced. Two plungers, C D, formed of soft iron, are mounted on a balance lever, F. The ends of the coils are connected with the balance lever in such manner that as each end rises and falls alternately, it reverses the direction of the voltaic current through the coils, similar to the arrangement shown in fig. 124, and thus reverses the poles of magnetic attraction. In the position represented, the plunger D having reached the centre of the coil, where there is no magnetic action, the direction of the electric current is reversed by the lever, and C is then attracted into the hollow coil A. The lever is thus alternately lifted up and down, like the beam of a steam engine, the two hollow coils representing the two cylinders.

By this means of applying the force of induced magnetism the sphere of attraction is very much increased, especially when permanent steel magnets are used as plungers, for it then extends near to the centre; and as the attractive power in one of the coils diminishes, the repelling power of the other is correspondingly increased. We have not heard of any practical application of this form of electro-magnetic engine; but it is a new mode of applying the force of electro-magnetism, which promises to be attended with favourable results.

In the Reports of the Juries of the Great Exhibition an electro-magnetic engine, invented by Mr. Hjorth of Denmark is highly spoken of. It operates on the same principle as the engine we have just noticed. It consists of two sets of hollow horse-shoe electro-magnets, conical inside, with a corresponding number of solid electro-magnets, which, by mutually attracting each other, make a double stroke of four inches in length. The power has been found, by means of a spring-balance, to be about thirty pounds at the commencement of the stroke when the distance of the respective poles is about half an inch, decreasing slightly by degrees as the piston enters into the hollow electro-magnet.* The Jury state, "we cannot help flattering ourselves that the attainment of this mysterious motive force will soon be followed by making it available for practical purposes."

BLASTING ROCKS.

When a voltaic current is transmitted through a thick wire, it is conducted so freely that there is no sensible increase of heat. But if a very thin wire be interposed in the circuit, the resistance thus offered to the electric current causes the evolution of

* *Reports of the Juries*, class X., p. 25

heat sufficient to make the wire red hot. This heating property of the voltaic current has been rendered available in blasting rocks. Thick wires from a voltaic battery containing a series of plates of not less than four inches square are laid down to the spot where the explosion is to take place, and at that point the circuit of thick wire is broken, and a short length of very fine platinum wire is introduced. The fine wire is usually inserted in a cartridge of gunpowder, and it is covered over by the powder to be exploded. When everything is properly arranged and all persons have retired to safe distances, the thick wires are connected with the two poles of the battery, and the powder is instantly exploded.

This plan of blasting rocks is more effectual and more free from danger than the ordinary method of igniting the powder by a fuse, for it sometimes happens that the lighted fuse communicates with the powder before the time calculated; occasionally also it hangs fire, and the men, supposing it to be extinguished, approach the mine and are killed by the unexpected explosion.

The application of voltaic electricity to the purposes of exploding large charges of powder was first successfully made by Colonel Pasly in blowing up the wreck of the Royal George, and it has since been generally employed for submarine explosions. The most remarkable instance of this application of electricity was the removal of an immense mass of the Round Down Cliff at Dover, on the 26th of January, 1843. The cliff was 375 feet above high-water mark; and as a projection of it prevented a direct line of the South-Eastern Railway being taken to the mouth of the Shakespeare tunnel, it was resolved to remove the obstruction by blasting. Three different galleries and three shafts connected with them were excavated in the chalk rock. The length of the galleries was about 300 feet, and at the bottom of each shaft was a chamber eleven feet long, five feet high, and four feet six inches wide. In these chambers 18,000 pounds of gunpowder were placed in bags, with the mouths open and loose powder scattered over them. The distance of the charges from the face of the cliff was about seventy feet. At the back of the cliff a wooden shed was constructed in which three voltaic batteries were arranged. Each combined battery consisted of eighteen of Daniell's cells and two common batteries of twenty pairs of plates each. To these batteries were connected thick wires, covered with cord to insulate them from the ground. The wires were laid upon the grass to the top of the cliff, and then falling over it were carried to the eastern, the central, and the western chambers. The wires were

each 1,000 feet long, and it was ascertained by experiment that the electric current was sufficient to heat the interposed length of platinum wire at a distance of 2,300 feet. The powder was divided into three charges, each one being exploded separately by a distinct circuit, it being arranged that at the instant the central charge was fired, the voltaic current should also be transmitted through the two other circuits. Flags were fixed at various points on the cliffs to warn people not to approach, and on the top of the Round Down Cliff a larger flag was planted, towards which all eyes were directed as the time appointed for the explosion approached. "At twenty-six minutes past two o'clock," as reported in the *Times* of the following day, "a low, faint, indistinct, indescribable, moaning, subterranean rumble was heard, and immediately afterwards the bottom of the cliff began to belly out, and then, almost simultaneously, about 500 feet in breadth of the summit began gradually but rapidly to sink. There was no roaring explosion, no bursting out of fire, no violent and crashing splitting of rocks, and, comparatively speaking, very little smoke; for a proceeding of mighty and irrepressible force, it had little or nothing of the appearance of force. The rock seemed as if it had exchanged its solid for a fluid nature, for it glided like a stream into the sea, which was at the distance of 100 yards, perhaps more, from its base." The top of the Round Down Cliff did not fall down on to the beach as might have been expected, but it descended almost perpendicularly, retaining its former distinctive character at a lower level than the surrounding cliffs which it before overtopped. By this blast one million tons of chalk were removed, which would have otherwise required twelve months' labour to cut away.

EXPLOSION OF FIRE-DAMP IN MINES.

The same arrangement that is adopted for blasting rocks might be applied, with great effect, to diminish the loss of life occasioned by explosions of carburetted hydrogen gas in coal mines. It is the practice in many mines that are considered to be "fiery," for a man to descend every morning, before the miners go to work, to ascertain whether the passages are in a safe condition. The duty of the "viewer" is to proceed to all the dangerous parts with a safety-lamp, and if he finds from the indications of the flame within the wire gauze that the atmosphere is inflammable, the miners are not allowed to descend until additional means have been taken to ventilate the mine. This duty is sometimes very negligently performed, and the miners

not unfrequently accompany the viewer with unprotected candles.

The trouble and loss of time of this precautionary examination and its accompanying danger might be saved, by igniting lucifer matches, or other combustibles, by voltaic electricity in various parts of the mine. This might readily be done at a very trifling cost. A thick insulated wire fixed to the side of the shaft from the mouth of the pit to the farthest part of the workings, and there attached to a copper plate immersed in a pool of water, would serve to conduct the current of electricity, and the return current might be completed by a similar plate of metal buried a few feet deep in the moist earth near to the battery at the pit's mouth. By intercepting the thick wire circuit in those parts usually most dangerous, and introducing a short piece of very fine platinum wire, heat sufficient would be evolved at those points, when the circuit was completed through the battery, to ignite lucifer matches laid upon the fine wires over night. By this means the condition of the mine could be ascertained in an instant, without personal examination.

There would of course be objections raised to any plan so different from the usual routine, but it appears to present an easy, safe, and practicable mode of testing the safety of coal mines, which it would be advisable, at all events, to try.

SOUNDING THE SEA.

In sounding the sea by "the lead" at great depths, it is difficult to ascertain exactly when the weight strikes the ground. An ingenious contrivance has been invented by Mr. Bain for removing the difficulty by employing electrical agency. We are not aware that the invention has yet been brought into use; but it may be desirable to explain the *modus operandi* as an illustration of one of the many different ways in which electricity may be applied.

Fig. 126.

In fig. 126, a represents a metal spring-hook, the curved end of which c presses against the projection when the two points are not kept apart by the weight

lead, as they are represented to be in the woodcut. The end *e* is insulated from the other part of the hook by a piece of wood at *d*. A wire *g*, connected with the end *e*, proceeds from one of the coils of an electro-magnet on the deck of the ship; the wire *f* proceeds from a voltaic battery to which the other end of the coil of the electro-magnet is attached. By this arrangement it will be perceived that when the points *e* and *c* come in contact, the electro-magnet will become active; and the keeper, as it is attracted, may strike a bell, or give notice in any other convenient way. This would take place as soon as the lead touched the ground, for its weight would then cease to operate against the action of the spring in keeping the two ends apart; and by this means the instant that the bottom was reached would be made known.

For the sake of showing the action more clearly the two wires are represented in the figure as entirely separated; but they might be both twisted together round the plumb-line, if care were taken to insulate them from each other by a covering of gutta percha.

DETERMINING LONGITUDES.

Instantaneous communication from place to place, by means of electricity, has been applied to determine the longitude. This was first done in America at great distances apart, and afterwards in this country; Professor Challis, of Cambridge Observatory, having undertaken a series of experiments, in connection with the Royal Observatory at Greenwich, for that purpose. The principle on which this application of electric force depends is very simple. A telegraphic wire was connected with the observatory at each place, and the instant that the seconds-hand of the clock at Greenwich indicated a given time, a signal was transmitted through the telegraph wire, and the Cambridge time was directly noted. The difference between the two affords the means of determining the longitude with great exactness, by showing how much sooner the sun comes to the meridian at Cambridge than at Greenwich.

FIRE ALARMS.

Electro-magnetism has been ingeniously applied to sound an alarum in case of fire. The action of the instrument depends on the well-known expansion of mercury by heat. The mercury is contained in a glass bulb similar to the bulb of a thermometer; and when heated it rises up the tube and touches a wire which is connected with a voltaic battery, and instantly brings into

action an electro-magnet. A detent is then withdrawn from a clock-mechanism, and an alarum is thus sounded whenever the room in which the thermometer-instrument is placed becomes heated much above the ordinary temperature.

In the accompanying figure A represents the glass bulb; B C two short tubes communicating with it, into which wires are introduced. The bulb is filled with mercury, and placed in a vertical position, so that when the mercury is expanded by heat it will rise in the tube and touch the wire. The wire at the bottom is connected with the electro-magnet, and that at the top with the voltaic battery; and in this manner the circuit is completed as soon as the mercury becomes sufficiently expanded to rise as high as the wire C.

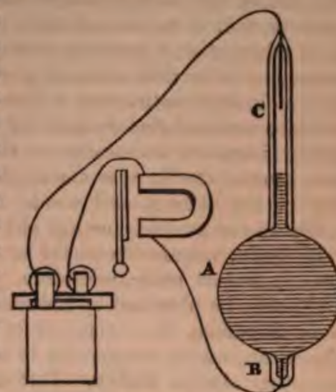

Fig. 127.

A thermo-electric alarum might at very trifling cost be placed in every room of a house, one voltaic battery and one loud alarum being sufficient for all. In hotels, and in all large establishments, an apparatus of this kind would prove a great safeguard, as it would be the means of giving warning of danger before any indication of fire was otherwise perceptible.

TABLE-MOVING.

As the alleged phenomena of table-moving, which have attracted much attention, have been attributed to electrical agency, it might be considered an omission in this work if the subject were not noticed. We have no hesitation in asserting, that it is absolutely impossible such effects could be produced by the known properties of electricity. Even admitting—which we are far from being inclined to do—that electricity can be excited by the imposition of hands, and that it could be so excited in unlimited abundance, no accumulation of electrical force could operate in such a manner on a solid table placed upon the floor.

Let us consider for a moment the physical circumstances necessary to produce the simplest of the movements stated to occur. To raise a table on one side a few inches from the ground

by electrical attraction would, in the first place, require a greater amount of electric force than was ever generated by the most powerful artificial means. Such a concentration of electricity could not fail to exhibit itself by the emission of sparks, by the attraction of all surrounding moveable objects, and by the repulsion of any light bodies placed upon the table. No such effects are represented to be exhibited; and we are told that tables move without any previous manifestation of the ordinary phenomena of electrical attraction. It is also irreconcilable with all the known actions of static electricity, to suppose that it could be accumulated in quantity and intensity on such an imperfect insulator as a carpet. Even if that were possible, the attraction of the floor, as the nearer object, would greatly surpass that of the ceiling, and would therefore hold the table more firmly to the ground, instead of lifting it up.

If, again, voltaic electricity be the assumed agent, the difficulties are no less insurmountable. Attractive power in that case could only be obtained by inducing magnetism. We must suppose, therefore, the existence of some undiscovered property, which can impart magnetism to wood, and is capable of attracting other similar bodies. But even admitting all this, a cause would still be wanting to account for the magnetized table being attracted to the more distant ceiling, instead of to the floor.

In addition to those inventions we have described, there are numerous other applications of electricity: some of which, however, are of little practical utility, and in other cases the practicability of the applications of the force is too questionable to render it requisite to give special descriptions. Among the variety of objects to which electricity has been applied may be mentioned a means of measuring the velocity of cannon balls, and of other rapidly moving bodies; a mode of performing on musical instruments; the detection of the frauds of omnibus-conductors; and a plan for catching whales. The last-named invention we have only recently seen noticed, and if feasible, it will certainly afford great advantage to the arctic fishermen. The harpoon is to be connected by a wire to a voltaic battery, and the instant it strikes a whale it is to communicate a stunning shock that will render the creature powerless.

It is impossible to conceive limits to the extent to which electric force may be applied by the ingenuity of man as progress continues to be made in the science, and especially when more *facile* methods of generating electricity are discovered. Its im-

portance as a means of transmitting intelligence is becoming daily more appreciated; and when the electric telegraph has received the improvements of which it is already capable, it will become a general means of correspondence. The other object to which we look forward at present as most likely to effect important changes in the social condition of mankind is, the application of electricity as a moving power. The practical part of the science is not yet sufficiently advanced to enable us to expect an early approach of this event; but we feel assured that not many years will have passed before means will be found of employing electric force with great advantage for that purpose; and when that time arrives, changes will be effected in the means and facilities of locomotion, as great as any that have been introduced by the power of steam.

CHAPTER VII.

ON THE USE OF ELECTRICAL APPARATUS.

As it frequently happens that the student of electricity fails to manage even the simplest forms of apparatus from the want of practical knowledge, it has been thought desirable to append to this treatise on electric science, some plain directions that may assist in removing the difficulty.

In experiments with frictional electricity, the principal cause of failure arises from the deposition of moisture from the atmosphere, which prevents electrical excitement by rendering the surfaces of electrics imperfect conductors. Too much attention cannot, therefore, be paid to making every part of the apparatus, especially the rubbers, perfectly dry. In a damp state of the atmosphere it is almost impossible, even with the utmost care, to produce effects that may be readily obtained in clear frosty weather; and it becomes then more necessary to have all parts of the apparatus warm, as well as dry, to prevent the moisture in the air from condensing upon them. The moisture arising from the respiration of several persons in a room, and from the burning of candles or gas, is also very prejudicial to the excitement of electricity; consequently, when many persons are present and the room is well lighted, it is desirable to keep the apparatus near a fire till the moment it is required for use. At all times breathing on the rubber or glass should be avoided.

In the primary experiment of exciting a glass rod by friction with a silk rubber, care should be taken to have several folds of silk between the hand and the glass, otherwise the moisture of the hand will penetrate the silk and obstruct the excitement of electricity, and a portion of that which is excited will escape through the thin silk to the hand. A flannel pad covered with silk will be found most efficacious. Spread some amalgam, or, what is better, a little *aurum musivum*, upon it, and then, after holding the rubber and the glass rod to the fire for a short time, give the rod three or four brisk movements upon the rubber, to and fro from end to end, and there will not fail to be a copious excitement of electric sparks and flashes, accompanied by

snapping noises, arising from the electricity darting into the air or passing over the edge of the rubber to the left hand.

The experiment with a downy feather and an excited glass rod (page 56) frequently fails in damp weather, in consequence of the expanded fibres parting with the electricity to the surrounding air; consequently the feather does not become sufficiently charged with positive electricity to fly off from the rod. It is generally better, on this account, to substitute a strip of gold, silver, or copper leaf for a feather.

Before using the electrical machine, place it a short distance from the fire, remove the dust, and with a dry warm silk handkerchief rub the insulating glass pillars. Then apply a little amalgam to the rubber, by spreading it on with a blunt knife, make the rubber press lightly on the cylinder by adjusting the screw, and then the machine should be in good working order. After an electrical machine has been in use several times, small black specks collect on the glass, which should be scraped off, otherwise the action of the instrument will be impaired.

When the machine is in brisk action, there will be little difficulty in performing experiments illustrative of the phenomena of frictional electricity with the various kinds of apparatus noticed in the foregoing pages, the principal requisites being to keep all the parts dry and warm.

In the experiment with the glass tumbler and pith balls (page 58), if the surface of the table is much waxed or is French polished, those non-conducting surfaces may diminish the briskness of the action, because the connection with the earth is thereby rendered imperfect. It is advisable, therefore, to spread a sheet of tin foil on the table to rest the glass upon; for by thus exposing a large conducting surface in contact with the table there will be better conduction between the pith balls and the floor. In delicate experiments, indeed, it is desirable to have a direct metallic connection with the earth, by joining a wire from the apparatus to the gas fittings of the room, if there be any, or to the fire grate; for the carpet or wooden floor will obstruct the passage of electricity when it possesses a low degree of intensity.

In giving a shock, the Leyden jar should rest on the table after it is charged, and the person to whom the shock is to be given should hold in each hand a piece of metal—a metal spoon, for instance—with which he should first touch the outside coating of the jar, and then the knob. It is better to avoid seizing hold of the jar with the hand, because there is some danger of its being knocked down by the convulsive movement of the arm. When several persons are to receive a shock

together, they should take hold of hands, and the two outermost should touch the jar, taking care that the outside of the jar is touched before the knob. If it be required to send a shock through any particular part of the body, the end of a chain or wire that is connected with the outside of the Leyden jar should be applied to one point, and a knob of the insulating discharging rod (fig. 32) to the other; and by then bringing the discharger to the knob of the jar, it will be discharged through the part of the body which is thus interposed between the discharging rod and the chain.

Care should be taken not to give a shock so powerful as to be painfully unpleasant. Three or four turns of the handle of a small electrical machine will accumulate as much electricity in a Leyden jar as most persons will like to receive.

The experiment in which a second Leyden jar is charged by the overflow of the electricity from the first (page 96), may be easily performed with two jars only, which will show the effect nearly as well as three. The jar that is receiving its charge from the prime conductor being mounted on an insulating stand, hold the knob of the second jar near to the outside coating of the first, and a stream of sparks will pass between them. Both jars will thus be charged with positive electricity, and the second one, which receives all its electricity from the outside of the first, will be equally charged with the one that is connected with the prime conductor.

In performing experiments with the electrical battery, or with a large Leyden jar, caution will be required to avoid receiving an accidental shock; for though Franklin thought there was no danger in sending a powerful charge through the head, a shock of that kind might produce disagreeable consequences. It is always desirable to apply the discharging rod to the battery a second time to disperse the residual charge, which would often give an unpleasant shock.

In experiments with voltaic apparatus the state of the atmosphere is immaterial, nor is much attention necessary to insulation; the principal care required being to make perfect connections between the apparatus. The corrosion of the wires or the collection of dirt or grease on the united parts, will obstruct the action of the voltaic battery, and endanger the success of the experiments. The necessity for perfect connection arises from the low degree of tension of voltaic electricity, which has not energy sufficient to force itself through the thinest film of non-conducting substance. It is desirable, therefore, to have always at hand an old knife, to scrape the ends of the wires bright before connecting them to the binding screws, or twisting them together.

For experiments in electro-magnetism, or for showing the heating effects of voltaic electricity on a small scale, or for the demonstration of secondary currents, a Smee's battery will be found most convenient and manageable. A single cell, consisting of a pint jar, will be sufficient for showing the action of electro-magnetism, and the common intensity effects of the secondary current. When more power is required, a battery consisting of twelve pairs of zinc and platinized silver plates attached to a board, so that they may be together lowered into the exciting liquid or raised out of it by turning a handle at one end, is very convenient. Sulphuric acid diluted with twelve times its volume of water, makes a strong exciter; but for most purposes, a larger proportion of water, say 30 to 1 of acid, is more advisable, for there is then less waste of zinc by local action. For exhibiting the more powerful effects of voltaic electricity, larger plates in greater numbers should be employed, and a series of cells of Daniell's battery will be found less costly in the first instance than Smee's. The nitric acid battery of Mr. Grove's arrangement is more powerful than either; but the evolution of the fumes of nitrous gas makes that battery objectionable when the experiments are not performed in a laboratory fitted with suitable convenience for its use.

In using a Smee's battery it is requisite to observe that the screws of the clamps that bind the zinc plates together are tight, and care should be taken that the platinized foil between the two zincs do not touch them, as sometimes happens.

When there is an evolution of gas in the cells at the time the battery connection is broken, it is a proof of local action, which wastes the zinc, and to prevent it the plates should be amalgamated. This is easily done with a Smee's battery, by unscrewing the plates and removing them, and then sprinkling a few drops of mercury over their surfaces, which may be rubbed with a cork or piece of cloth. The loose globules of mercury should be wiped off before the zinc plates are again screwed together; care being taken that none of the mercury touches the platinized silver.

In using a Daniell's battery, the solution of sulphate of copper should be maintained in a saturated state by keeping crystals of the salt in the outer cells, and the inner porous cells, which contain the acidulated liquid or solution of salt, to excite the zinc, should be rinsed out with warm water after being used, as they are liable to be clogged up by the oxide of zinc.

In arranging a series of plates to form a combined battery, the zincs and coppers must be placed alternately; commencing with a zinc plate in one cell, and a copper in the next, and

observing that there is a copper and a zinc in each. None of the plates should touch in the cells; it is also necessary to observe that not any one of the plates is defective or more corroded than the rest, for it must be borne in mind that the quantity of electricity generated by the combined battery will be proportionate to the quantity generated by the least operative plates of the series. The voltaic battery is, in this respect, like a chain, any single link of which being defective, the whole will be equally weak, how strong soever the other links may be separately. Want of attention to this fact frequently renders a seemingly powerful voltaic arrangement ineffective.

When the battery is in good action, there will seldom be any difficulty in performing experiments with voltaic electricity, provided the connecting wires and binding screws are clean and well united together. Particular attention should be paid to those points, as the cause of failure is most frequently owing to imperfect connections. Even the lacquer varnish on new apparatus is quite sufficient to interrupt the voltaic current, and often causes much annoyance; it should therefore be scraped off from all connecting parts. The ends of the binding screws, and the threads of the screws may also require to have the lacquer that sometimes covers them cleared away.

It is impossible to foresee all the difficulties that may arise to the student in performing experiments; but it is hoped that attention to the directions we have here given, in addition to those in other parts of this volume, will enable him to overcome most of the obstacles that are usually encountered in first attempts, and after a little practical experience in the use of apparatus, he will pursue his investigations with increasing interest and success.

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